CITY OF BALTIMORE
Sheila Dixon
Mayor

DEPARTMENT OF PUBLIC WORKS
David E. Scott
Director

BUREAU OF WATER AND WASTEWATER
WATER & WASTEWATER ENGINEERING DIVISION

Gwynns Falls Sewershed Evaluation Study Plan
Project 1032

Inflow and Infiltration Evaluation Report
Sanitary Sewer Overflow Consent Decree
Civil Action No. JFM-02-1524

August 28, 2008

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URS

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1.0 Introduction

On September 30, 2002, the City of Baltimore (City) entered into a Consent Decree with the U.S. Environmental Protection Agency, the U.S. Department of Justice, and the Maryland Department of the Environment (MDE) to eliminate all wet weather sanitary sewer overflows located in the City of Baltimore. In accordance with the Consent Decree, the City of Baltimore Department of Public Works began sewer system evaluation studies of the entire wastewater collection system. On June 20, 2007, the City contracted URS Corporation (URS) to complete an evaluation study for the Gwynns Falls sewershed. This report, which augments the evaluation study, analyzes the flow meter data to quantify hydraulic inflow and infiltration into the collection system. The inflow and infiltration analysis and preparation of this report were completed by George, Miles & Buhr, LLC (GMB), a URS subconsultant.

1.1 Sewershed Information

1.1.1 Study Areas

The Gwynns Falls Sewershed is one of eight sanitary sewersheds located within the City of Baltimore. The sewershed is located in the western portion of the City and extends west into Baltimore County (County). Although the area in the County flowing to the Gwynns Falls sewershed is extensive, this study covers only that portion located within the City limits (reference Figure 1-1) for Inflow & Infiltration (I&I) assessment. The sewershed area within the City consists of approximately 1.2 million linear feet of sewer 8" diameter and larger and 5,300 sewer manholes.

Figure 1-1 Location Map

In addition to the areas flowing directly to the Gwynns Falls Interceptors which includes the Dead Run Interceptors, Walbrook Interceptor, Forest Park Interceptor, and Powder Mill Interceptor, the area flowing to the Maiden's Choice Interceptors is also included as part of Gwynns Falls sewershed. The Maiden's Choice area is located in the southern end of the sewershed and does not flow directly into the Gwynns Falls Interceptors but drains to Low Level sewershed where the flow gets divided via pressure sewer to the Southwest Diversion and via gravity sewer to Back River WWTP.

At the lowermost end of the Gwynns Falls Interceptors, the Baltimore Street Diversion Chamber directs flow leaving the main Gwynns Falls sewershed to either the Back River WWTP or the Patapsco WWTP or splits between both. Flows directed to Back River WWTP leave the Gwynns Falls sewershed through the High Level sewershed and enter the main Outfall Interceptors to Back River. Flows directed to Patapsco WWTP leave Gwynns Falls via the Southwest Diversion which flows through the Low Level sewershed and Patapsco sewershed. The Southwest Diversion also picks up flows from the Patapsco Pump Station, and the West Port Pump Station (PA-13), before reaching the Patapsco WWTP. The majority of the Gwynns Falls sewershed can flow to either WWTP. Figure 1-2 shows the sewers of the Gwynns Falls sewershed.

1.1.2 Current / Recently Completed Sanitary Sewer Projects

During recent years, various improvements and development of new sanitary sewer infrastructure within the Gwynns Falls sewershed have taken place. These contracts include:

A. Powder Mill System Improvements

   i. Sanitary Contract No. 777 – Rehabilitation of Powder Mill Interceptor from Wabash Ave. South to the Baltimore City & County Line and from 500 Feet East of Northern Parkway to Eldorado Ave. (construction completed February 2005)

   ii. Sanitary Contract No. 804 – Rehabilitation of Collection System at Various Locations in Gwynns Falls Sewershed (construction completed June 2005)

B. Dead Run System Improvements

   i. Sanitary Contract No. 788 – Rehabilitation of Sanitary Sewers from Westhills Road Following Briarclift Road to the Dead Run Interceptor at Franklintown Road (construction completed May 2004)

   ii. Sanitary Contract No. 825 – Improvements to the Dead Run Interceptor and Relief Interceptor Along Franklintown Road from the City/County Line to Wetheredsville Road (construction completed May 2006)

C. Maiden’s Choice Interceptor

   i. Sanitary Contract No. 826 – Improvements to Maidens Choice Interceptor from Overbrook Rd. to Diversion Vault (MC 60) West of Caton Avenue (construction completed September 2006)

D. Forest Park System Improvements

   i. Sanitary Contract No. 780 – Replacement of Existing Forest Park Interceptor from 500 Feet West of Hillsdale Rd. to Intersection of Carleview Rd. and the Alley 210 Feet East of Hillsdale Rd. (construction completed October 2004)

   ii. Sanitary Contract No. 782
   (construction completed September 2002)

   iii. Sanitary Contract No. 813 – Improvements to the Sanitary Sewer System at Various Locations in the Forest Park Combined Sewer Area (construction completed June 2005)

E. Consent Decree (Appendix D) mandated projects:

i. SC 827 – Elimination of Siphon Blow-Offs 11 and 12 (construction completed June 2004)

For a graphical representation of these projects, refer to Figure 1-3.

SC 825 and SC 826 were completed during the flow metering program; all other construction contracts were completed prior to the flow metering program (reference Section 1.3.1).

1.2 Study Requirements

1.2.1 Consent Decree and BaSES Manual Requirements

The analysis contained in this report was completed in accordance with Section VI, Paragraph 9.E of the Consent Decree and Section 3 Infiltration and Inflow (I&I) Evaluation of the City of Baltimore Sewer Evaluation Standards (BaSES) Manual.

The flow meter data was divided by flow meter drainage area into individual flow components of Sewage, Base Infiltration, and Rainfall-Dependent Infiltration and Inflow (RDII) and analyzed for two purposes:

i. I&I Analysis- Identifying/quantifying/locating Base Infiltration and RDII.
ii. Hydraulic Modeling- Developing flow inputs for hydraulic model.

Following the procedures and guidelines presented by Section 3 of the BaSES Manual, the following tasks were completed in the development of this document:

A. Pre-Analysis

i. Map Connectivity/Subtractions
ii. De-Selecting Data

B. Dry Weather Analysis

i. Data Selecting
ii. Removing Atypical Days

C. Wet Weather Analysis

i. Precompensation
ii. Rain Total to RDII Volume
iii. Normalizing and Ranking RDII

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1 inch equals 5,000 feet

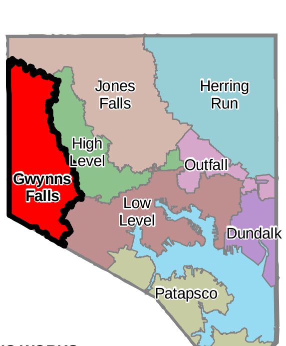

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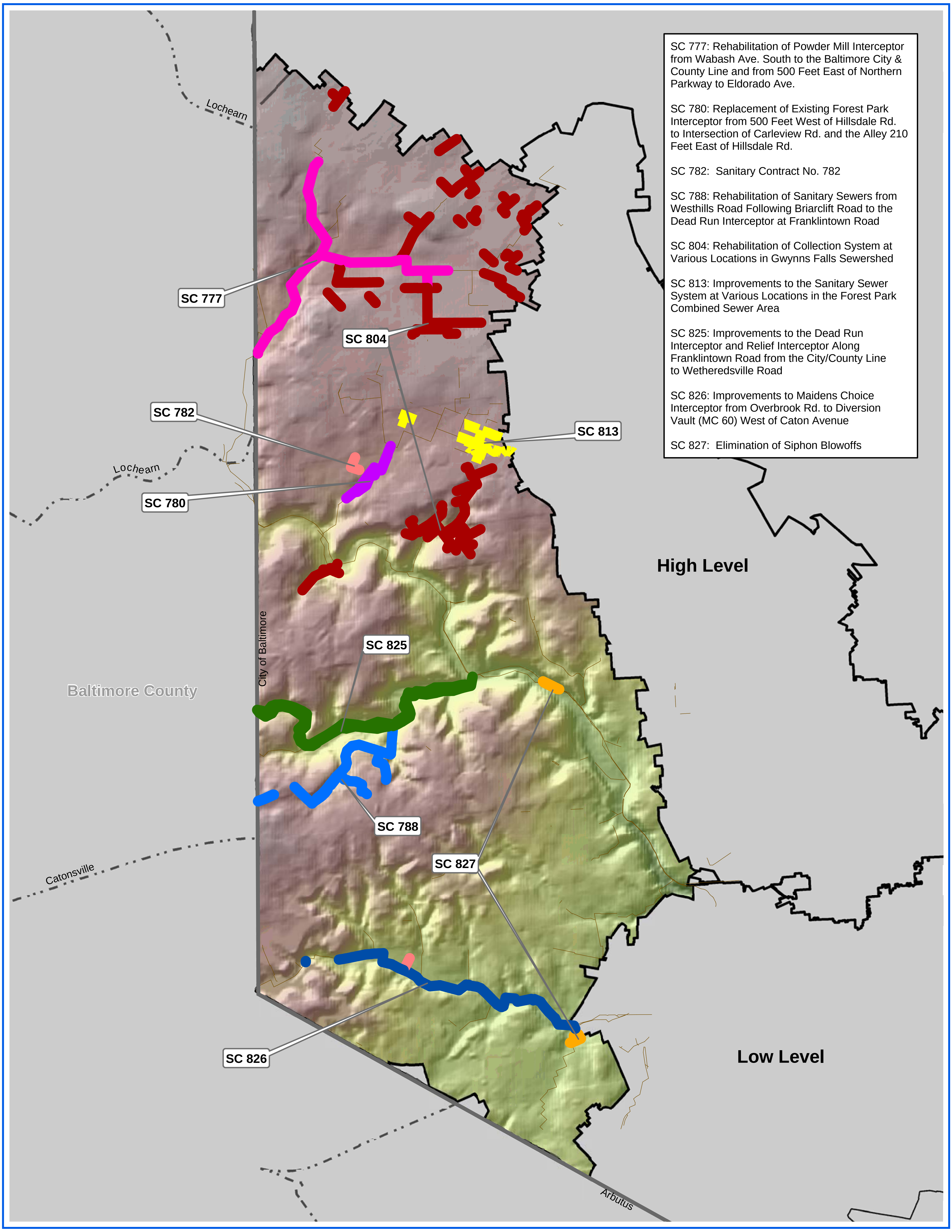
Figure 1-2
Collection System Location Map



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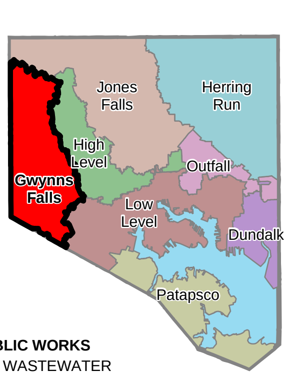

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LEGEND

CONTRACT NUMBER

777	788	825
780	804	826
782	813	827

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Figure 1-3
Current/Recently Completed Sewer Construction Contracts Location Map

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1.3 Flow Metering Summary

1.3.1 Flow Metering Period

The analysis included in this report was based on the flow meter data collected in the Gwynns Falls Sewershed which was collected by the City-wide flow metering program. In accordance with the Consent Decree, the City's flow metering program consisted of three phases:

A. Phase 1: The 18-month flow metering program which began prior to the construction of the Consent Decree Paragraph 8 mandated interceptor projects (listed in Appendix D of Consent Decree). During this phase, approximately 100 flow meters were installed at various locations throughout the City. Data from this flow meter phase was not used for the analysis included in this report.

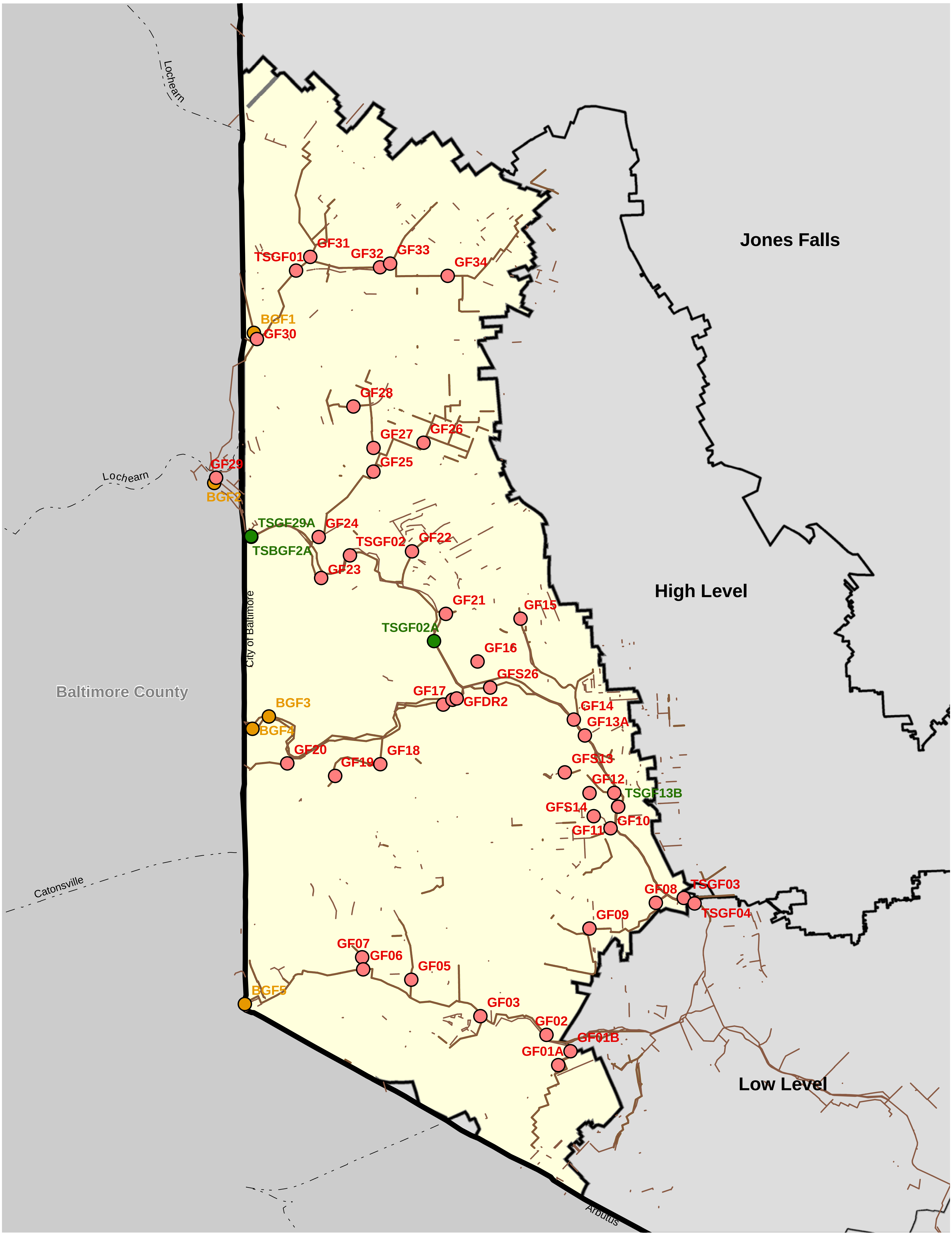
B. Phase 2: The 12-month flow metering program which began on May 9, 2006 and ended on May 18, 2007 (the original 18-month duration required by the Consent Decree was shortened with the approval of all signatory parties). During this phase, approximately 366 flow meters were installed at various locations throughout the City. Fifty-three (53) of those flow meters were installed in the Gwynns Falls sewershed.

C. Phase 3: This will be an 18-month flow metering program to be completed at a later date to assess the effectiveness of improvements to the system.

The Phase 2 flow metering locations for the Gwynns Falls sewershed, established under City of Baltimore Project No. 995 by RJN Group, are displayed in Figure 1-4. A flow metering schematic indicating flow meter locations in relation to each other and sewer connectivity is provided in Figure 1-5.

Concurrent with the Phase 2 flow metering program was a rain gauge data collection program also completed by RJN Group. The seven rain gauges located in and around the Gwynns Falls sewershed are shown in Figure 1-6.

In addition to the Phase 2 metering performed in Gwynns Falls sewershed May 2006 to May 2007, the City has extended the duration of twenty (20) flow meters and added four (4) supplemental flow meter sites, all of which are listed in Table 1-1. The extended sites are Phase 2 flow meter sites that were left in place when the majority of sites were removed. The supplemental flow meter sites are new sites that were not previously metered. Both extended and supplemental flow meter sites were in place after the main flow metering effort under Phase 2 was discontinued. However since this additional flow metering was performed at a different time, its data cannot be used in conjunction with the previous flow metering for I&I analysis and therefore has not been analyzed as part of this I&I report.



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1 inch equals 3,000 feet

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- I&I FLOW METER
- BORDER FLOW METER
- SUPPLEMENTAL FLOW METER
- >12" SANITARY SEWER

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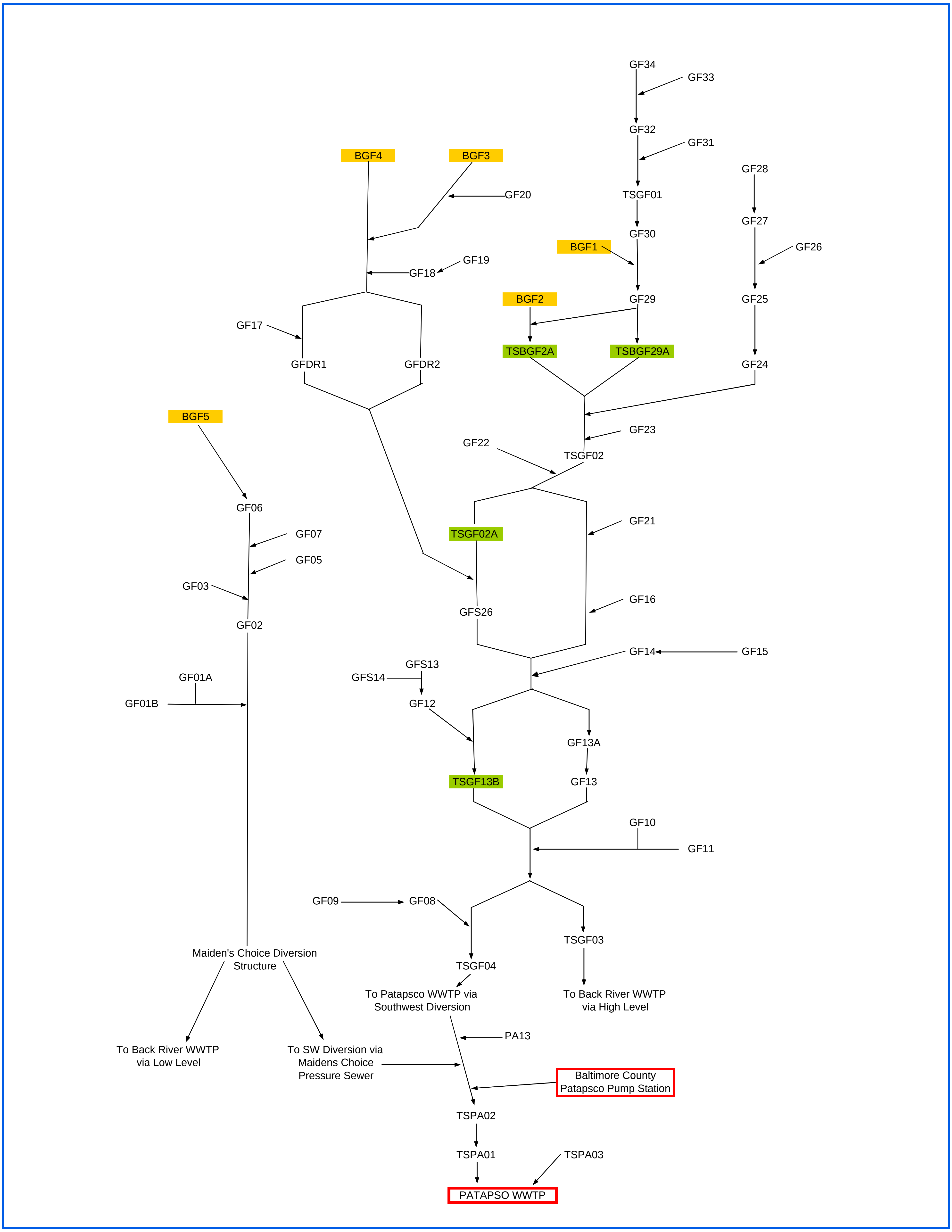
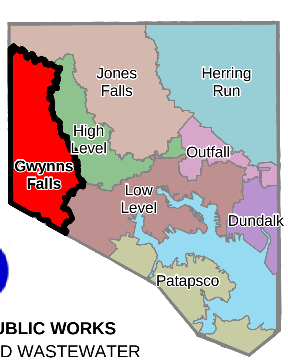
Figure 1-4
Flow Meter Location Map





BORDER FLOW METER

SUPPLEMENTAL FLOW METER

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Figure 1-5

Flow Meter Schematic

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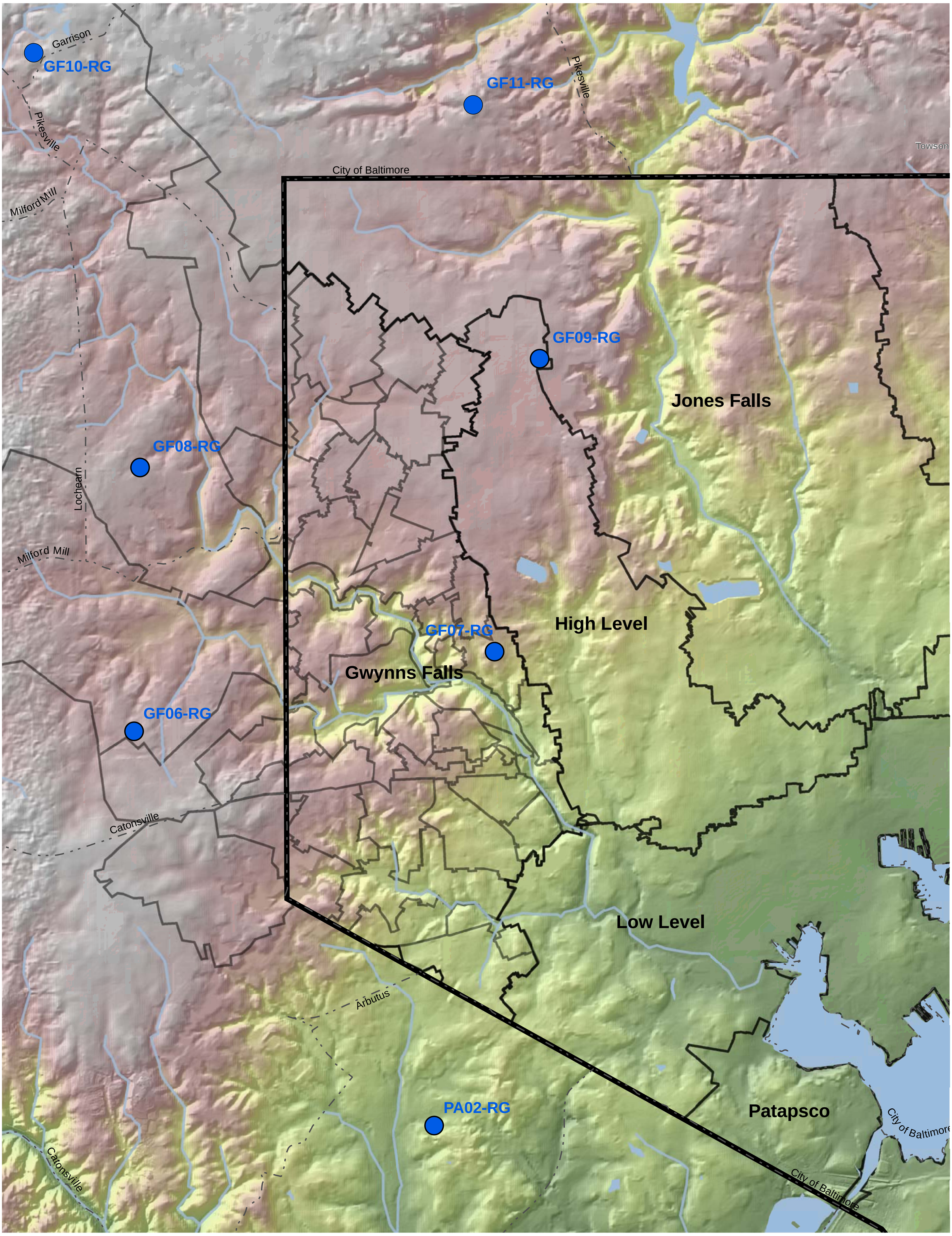

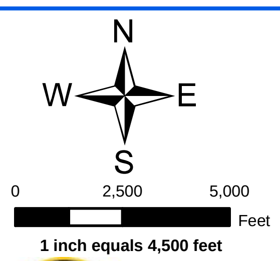

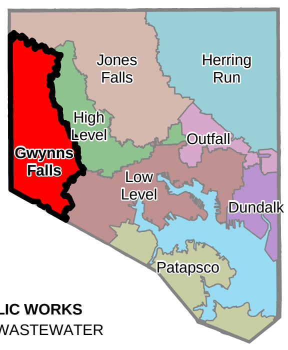

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RAIN GAUGE LOCATION

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Figure 1-6
Rain Gauge Location Map

Table 1-1
Extended and Supplemental Flow Meter Sites

EXTENDED FLOW METER SITES
BGF1
BGF2
BGF3
BGF4
BGF5
GF01A
GF13
GF24
GF29
GFDR1
GFDR2
GFS26
PA13
TSGF01
TSGF02
TSGF03
TSGF04
TSPA01
TSPA02
TSPA03
SUPPLEMENTAL FLOW METER SITES
TSBGF2A
TSGF02A
TSGF13B
TSGF29A

1.3.2 Data Flow Summary

The Phase 2 flow meter data was reviewed for quality assurance/quality control (QA/QC) by the flow meter consultant. After the initial review, the data was reviewed again by the City's technical program manager. Approved data was then made available to the sewershed consultants through Sliicer.com as referenced in the BaSES Manual (reference Section 3.1) for analysis. The rain gauge data was collected, reviewed for QA/QC, and approved for distribution and use in a similar manner.

2.0 Data Collection

2.1 Data Collection Purposes

The recorded flow meter data was used for inflow and infiltration analysis and for developing inputs for hydraulic modeling. The infiltration and inflow analysis quantified extraneous flow entering the sewer collection system in the form of Base Infiltration and Rainfall-Dependent Infiltration & Inflow (RDII) for each flow meter basin. Flow meter drainage basins were then ranked for inflow and infiltration severity.

As part of the field investigation phase, the Gwynns Falls project team will proceed to further investigate areas identified having high RDII through the use of field-locating techniques such as smoke testing.

The recorded flow meter data will be used to develop and calibrate a dynamic hydraulic model (the micro-model). This model will assist in the evaluation of existing and anticipated future capacity conditions under multiple design scenarios in order to develop recommendations for improvements. Hydraulic model inputs derived from the flow metering data consist of the following:

A. Sewage Flow

B. Base Infiltration (BI)

C. Rainfall-Dependent Infiltration & Inflow (RDII)

At a future date, the City will combine the micro-models from the various sewersheds into one City-wide model, referred to as the macro-model, to simulate hydraulic conditions of the City's entire wastewater collection system. Accordingly, the City has identified three distinct Phase 2 flow meter designations:

A. Micro / I&I Flow Meters:

The data from these flow meters was used to develop the hydraulic model for 10-inch diameter and larger sewers (with the exception of those sewers developed using the macro-flow meters).

B. Macro / Trunk / Model Calibration Flow Meters:

Flow meters placed on the primary interceptors used to develop the hydraulic macro-model. Flow meter identifications prefixes such as BGF (Border Sewer), TSGF (Trunk Sewer), or GFS (Inverted Siphon) are designated as macro-meters. In general, the macro-flow meters are installed along the Gwynns Falls parallel interceptor sewers. Macro meters were also used to quantify flows entering from outside the City.

C. Supplemental Flow Meters:

Upon completion of the main flow metering program from May 2006 to May 2007, the City continued to operate some flow meter sites as supplemental flow meters. These supplemental meters were not applicable for the infiltration and inflow analysis since they were in service at a different time from the main Phase 2 flow metering program.

2.2 Drainage Basin Data

The individual flow meter sites and their respective drainage areas are shown in Figure 2-1. Drainage basin data such as sewer length, surface area, etc., were provided in the Sliicer analysis software. The data was from the City's Geographic Information System (GIS) as it was during the flow metering period from May 2006 to May 2007. The flow meter basin data provided in Sliicer was compared with the GIS data provided to the sewershed team by the City. During the analysis phase, the Sliicer and GIS data sets were determined to be identical. The GIS has since been updated to be more complete and accurate, however, the GIS data in Sliicer has not been updated. For this report, the sewer lengths, surface areas, etc. used in the comparisoin calculations are based on the latest GIS data available at the time of this writing, not the outdated GIS data used in Sliicer.

The flow meter drainage data used in the analysis for flow comparisons was the best available at the time. This data may be updated at a future date which may or may not affect the comparisons and rankings presented in Chapter 4.

2.3 Flow Meter Analysis & Applications

With the exception of the supplemental flow metering, all flow meter site locations were selected by the City based on a pre-determined sewer linear footage criteria (reference BaSES Manual Section 3.2.2)

2.3.1 Flow Meter Sites

All of the flow meters collected data in 5-minute intervals. A Site Report for each flow meter is included in Appendix 2-1.

2.3.2 Flow Meter Description

2.3.2.1 Flow Metering Methodology

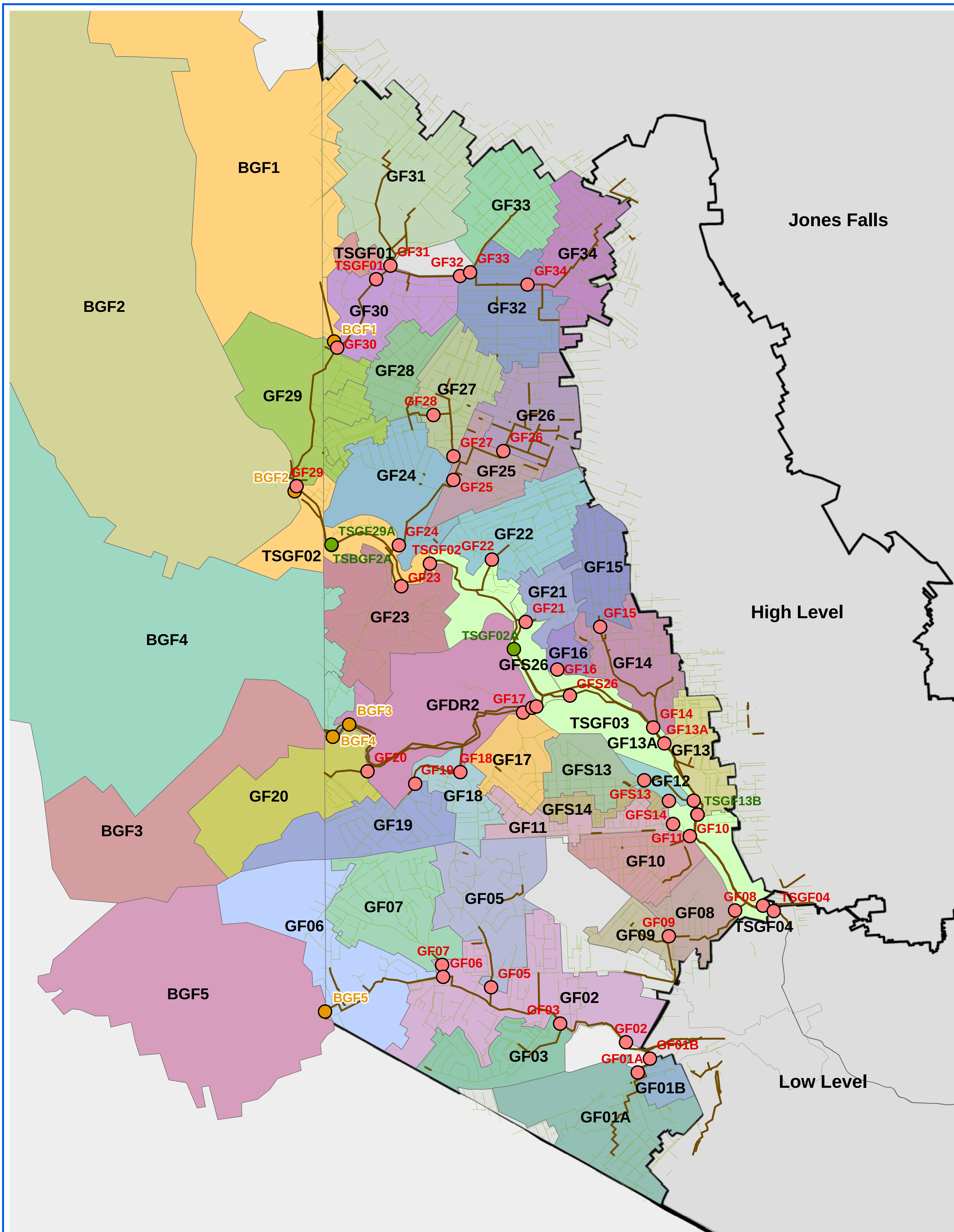
Flow meters record flow velocity and depth to calculate the flow rate using the Continuity Equation:

$$Q = V A$$

Where: Q = flow rate (ft^3/second)

V = average flow velocity (ft/second)

A = cross-sectional flow area (ft^2)



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1 inch equals 3,000 feet

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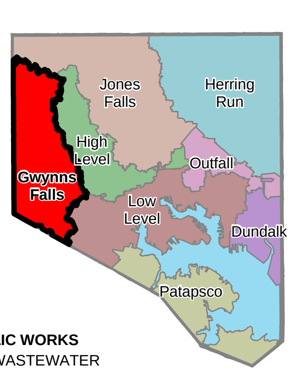

LEGEND

- I&I FLOW METER
- BORDER FLOW METER
- SUPPLEMENTAL FLOW METER

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Figure 2-1
Flow Meter Drainage Basin Location Map

In a pipe of known diameter, the cross-sectional flow area is determined by recording the depth of flow and mathematically calculating the cross-sectional area occupied by the flow.

Depending on the manufacturer, the flow meter may include a single or multiple sensors which are located in or above the flow. Sensors located in the flow are susceptible to debris/deposition fouling while sensors located above the flow may provide false or no readings during surcharge conditions or if there is foam on the water surface. Sensors located above the flow in manholes are the most unreliable as the data is recorded in the manhole channel, not in the sewer pipe. Typically, the flow is more turbulent at the pipe/manhole wall interface which can affect the readings.

Velocity-reading technologies vary between flow meter manufacturers but are typically more prone to error than depth readings regardless of type. For most flow meters, the velocity sensor records flow velocity at a point in the flow, which it then converts into an average velocity that is representational of the entire flow. Typically, the recorded-to-average velocity relationship is established during installation by velocity profiling across the flow cross-section. Velocity profiling requires recording multiple velocity readings at various depths and points across the width of the pipe and calculating the recorded-to-average velocity relationship. However, the relationship is typically based on the most prevalent hydraulic conditions and may, therefore, be less accurate for other flow conditions such as very low or high flows.

Depth-reading technologies for flow meters typically rely on ultrasonic or pressure sensors to determine the depth of flow. In a pipe of known shape and dimensions, the depth of flow translates into a cross-sectional area. In general, depth readings are considered more reliable than velocity readings.

2.3.2.2 Flow Meter Equipment

Based on the flow meter site reports, FlowShark flow meters, manufactured by ADS Environmental Services, were installed at all of the flow meter sites in the Gwynns Falls sewershed. As shown in Figure 2-2, the velocity and depth sensors for the FlowShark flow meters are located at the same location in the flow which provides the most accurate data.

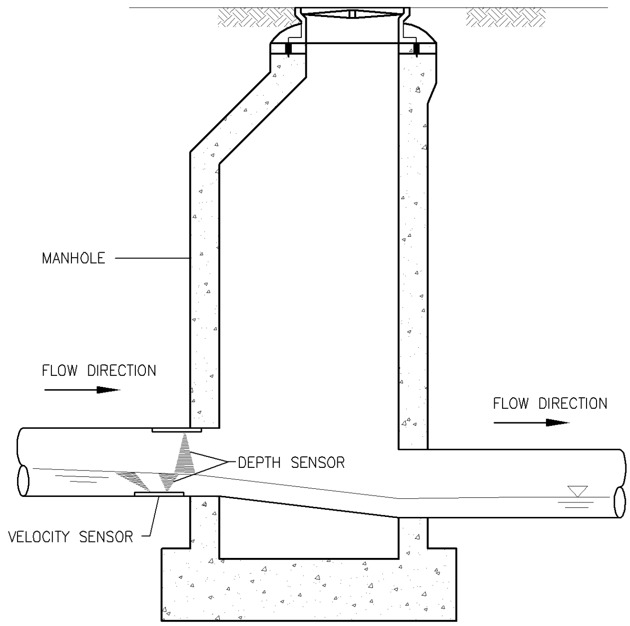


Figure 2-2 Typical FlowShark Flow Meter Installation

2.4 Rainfall Measurement

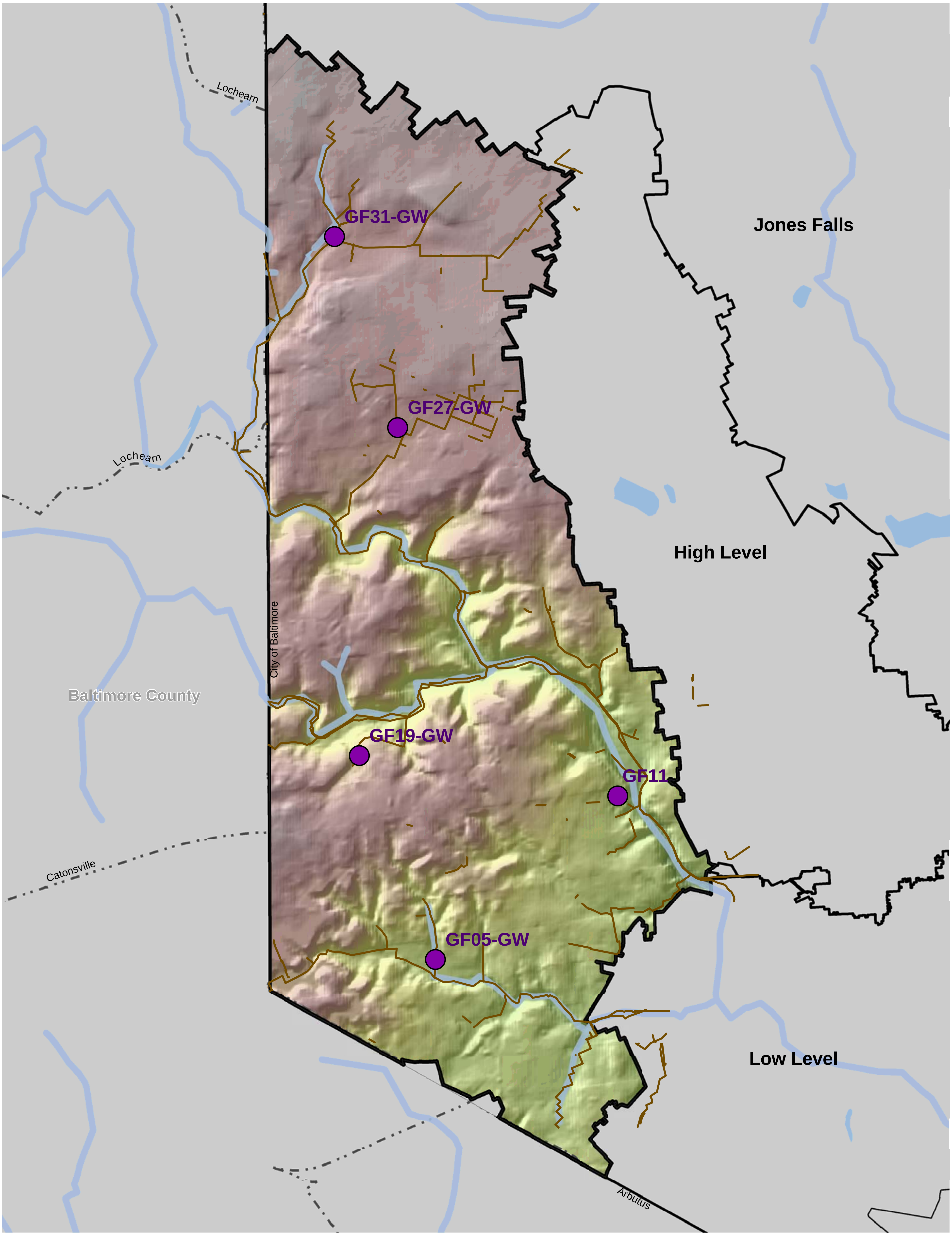
The City collected and provided ground-based tipping bucket rain gauge data in 5-minute intervals and 0.01 inch increments for the period May 9, 2006 through May 18, 2007 for use in the infiltration and inflow analysis. CALAMAR radar-rainfall data was procured for the same analysis period, however, it was not made available until April 4, 2008.

2.4.1 Rainfall Data Used in Flow Meter Data Analysis

Since the CALAMAR radar-rainfall data was provided late in the analysis schedule and would require extensive reconciliation with the rain gauge data, only the weighted ground-based rain gauge average, as calculated by the Sliicer software, was used to complete the flow meter data analysis. As a part of the analysis, the rain gauge and radar-rainfall data sets were compared at selected flow meter sites for various rainfall events to confirm similar general trends. The comparison was inconclusive since there appeared to be no consistent correlation between the two data sets. In some instances, the radar-rainfall data seemed to correlate with the RDII response better than the rain gauge data. Other occurrences revealed that the rain gauge data appeared to correlate with the RDII response better than the radar-rainfall data. In other cases, the data sets matched each other.

2.5 Groundwater Gauge Program Summary

Concurrent with the flow metering program, the City installed five groundwater gauges within the Gwynns Falls sewershed (reference Figure 2-3). The gauges were installed in the following manholes:



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Groundwater Gauges

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Figure 2-3
Groundwater Gauge Location Map

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A. Flow meter site GF05 manhole (Maiden’s Choice Interceptor)

B. Flow meter site GF20 manhole (Dead Run Interceptor)

C. Flow meter site GF27 manhole (Forest Park Interceptor)

D. Flow meter site GF31 manhole (Powder Mill Interceptor)

E. Flow meter site GFS21 manhole (Branch off Gwynns Falls Interceptor)

Groundwater gauge data is used to determine the relationship between groundwater elevation and base infiltration as derived from the flow metering data. As groundwater levels rise, base infiltration increases. However, the large collection system size and wide ground elevation variation in the Gwynns Falls sewershed precluded sewershed-wide groundwater simulation based on only five measured locations. Additionally, all of the groundwater gauges were located on the primary interceptors which, in general, are located in low areas where groundwater is likely to be present near the ground surface. Typically, groundwater flow rates in low areas remain relatively constant throughout the year and are not affected by seasonal weather variations. Based on consideration of the number and placement of the groundwater gauges, there was no reasonable relationship that could be derived between groundwater gauge data and base infiltration. Therefore, the groundwater gauge data was not used directly in the flow meter data analysis.

3.0 Flow Meter Data Analysis

3.1 Sliicer Flow Meter Data Analysis Program

As stated in Section 3 – Inflow and Infiltration (I&I) Evaluation of the BaSES Manual, the Sliicer.com flow meter data analysis application developed by ADS Environmental Services was to be used by all sewershed teams. The flow meter data was used for quality assurance / quality control review, inflow and infiltration analysis, and developing hydraulic model inputs.

Sliicer.com flow meter data was available for all the micro-meter sites. Discrete meter flows were derived by subtracting upstream metered flows from the reference meter to isolate each individual flow meter's drainage area and flow. The analysis was performed from the upstream flow meter sites to the primary interceptors. The Sliicer software incorporated the rainfall data to determine the rainfall-to-RDII relationship for each meter.

3.2 QA / QC Tools & Review

As part of the preliminary QA / QC review, various flow meter data components were analyzed to identify obvious discrepancies. Data components that were considered included:

A. Flow Balancing - Using the flow meter schematic, the gross average daily flow rates were compared to ensure that the flow totals increase at successive flow meters.

B. Hydrograph Analysis - Hydrographs of each site were reviewed, including depth and velocity readings, to ensure that flows conform to typical diurnal flow patterns consistent for the nature of the service area.

C. Scatter Graph Analysis - Scatter graphs (depth versus velocity) of each site were reviewed to ensure that flows conform to typical flow patterns or to investigate anomalies.

D. Flow Comparisons - Average rates for various flow components such as Base Infiltration and RDII were compared to drainage area characteristics such as length of sewer, surface drainage area, etc. to confirm that flows conform to typical flow ranges or comparative industry numbers.

As previously stated in Section 1.3.2, the flow meter raw data was reviewed by the flow meter consultant and the City's technical program manager with only the final data set being made available to the sewershed consultant through the Sliicer software. The sewershed consultant did not have access to the raw data prior to data modification (overwriting poor data with inferred data) or the field calibration logs. Therefore, there is no way to comment on the accuracy of the raw data or the appropriateness of the use of inferred data. Since the raw data accuracy cannot be validated, the effect of the QA / QC reviews detailed above cannot be quantified.

3.3 Other Flow Data Issues

3.3.1 Raw Data vs. Final Data

The flow meter data loaded in Sliicer was considered final data that had been processed by the individual flow metering contractor and approved by the City.

3.3.2 Flow Meters on Parallel Sewers

Of the three primary interceptors in the Gwynns Falls sewershed of Gwynns Falls Interceptor, Dead Run Interceptor, and Maiden's Choice Interceptor, all three have sections that consist of parallel interceptors.

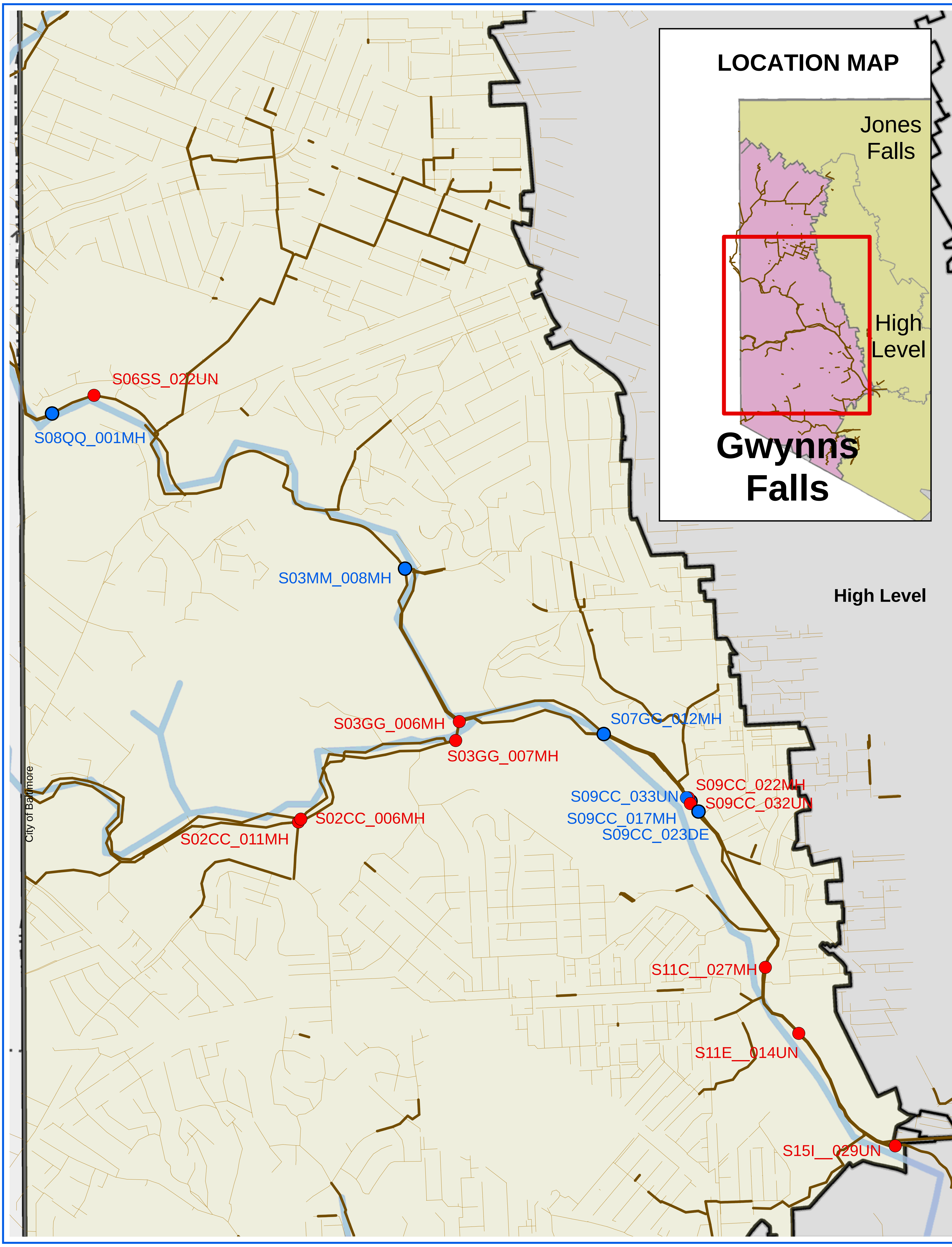
These parallel sewers include multiple common structures and inter-connections which allow flows to distribute between both sewers. This means that two different sewer lines share a common drainage area which flows to both lines. As such, flow meters on parallel sewers have to be deployed in pairs in order to record the total flow in both lines. There was one pair of flow meters located on parallel sewers – GFDR1 & GFDR2 on the Dead Run Interceptor. TSGF03 and TSGF04, located at the bottom of the Gwynns Falls Interceptor, also share a common drainage area. However because the interceptors diverge, flowing to different locations, and do not reconnect after these meters it is not considered a parallel meter set-up. Flow meters GF13, GF13A, and GFS26 were located on one leg of parallel sewers of the Gwynns Falls Interceptor but could not be fully utilized since the other leg of the parallel did not have a corresponding flow meter. The parallel portion of Maiden's Choice Interceptor did not have flow meters on either leg.

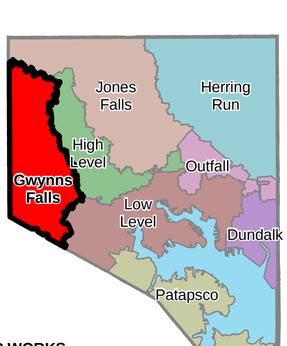
There are three types of inter-connections between the parallel sewer lines – shared manholes, diversion manholes, and piped inter-connections. Shared manholes have two pipes entering and two pipes exiting, diversion manholes have one pipe entering and two pipes exiting, and piped inter-connections are separate pipes between two manholes that help balance flow between the two lines. A location map of the structures and inter-connections is provided in Figure 3-1.

Since there are inter-connections between the parallel sewers, all of the upstream flow meter drainage areas must be considered tributary to each respective pair of flow meters. However, the Sliicer software was not configured to combine the respective drainage areas. Since the Sliicer program flow calculations are based on individual, rather than combined drainage areas, the resulting site totals were not considered reliable for the paired flow meters individually, only in combination.

3.3.3 Flow Meter Data Analysis Seasons & Daylight Savings Time

The Sliicer data analysis program divided flow meter data into summer and winter seasons to account for differing weather patterns over the course of a given year. Their respective periods of coverage corresponded to the Daylight Savings Time change. During the flow metering period, there were two time changes – October 29, 2006 Daylight Savings Time end and March 11, 2007 Daylight Savings Time start. This resulted in three analysis periods in Sliicer – Summer 2006 (May 9, 2006 to October 29, 2006), Winter 2006 / 2007 (October 29, 2006 to March 11, 2007), and Summer 2007 (March 11, 2007 to May 18, 2007).





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Diversion Manhole

Shared Manhole

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City of Baltimore
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Project No. 1032
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August 2008
Figure 3-1
Parallel Sewer Inter-connection Structures
Location Map

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All flow meters operated on Eastern Standard Time for the duration of the project as the flow meters were not re-set as part of Daylight Savings Time. Therefore, the Summer 2006 and Summer 2007 data sets are shifted by one hour compared to Winter 2006 / 2007 data.

3.3.4 Snow-Melt

There were no significant snowfall events recorded during the flow monitoring period. Therefore, there were no instances where snow-melt RDII could have occurred, which would be difficult to discern in analysis and could be mis-identified as Base Infiltration.

3.3.5 Flows from Baltimore County

Approximately 77% of the Gwynns Falls sewershed drainage area is located in Baltimore County, as shown in Figure 3-2, which equates to 26,055 acres in Baltimore County and 7,772 acres in the City of Baltimore for 33,827 acres total. County-contributed flows located west of the City have drainage areas including portions of both the City and the County. The list of flow meter site drainage areas that include both City and County flows combined is as follows: BGF1, BGF3, BGF4, BGF5, GF01A, GF02, GF03, GF06, GF19, GF20, GF29, and TSGF02.

Flow meter sites that included mainly County flows only were not included in the inflow and infiltration analysis except for the Powder Mill area due to its specific configuration. The Powder Mill area is located in the City but flows southwestwardly into the County before flowing southeastwardly back into the City. For a list of the Excluded County Flow Meters refer to Table 3-3.

Outside of the Gwynns Falls sewershed, parts of Baltimore County, Howard County, and Anne Arundel County flow to the Patapsco Pump Station, which then flows to the Southwest Diversion. The data for these flows and drainage basins is unavailable at the time, and thus not included in the I&I assessment. Therefore, the flow rates presented for the Southwest Diversion downstream of where the Patapsco Pump Station joins, including TSPA01, TSPA02, and TSPA03, do not include this subtraction and cannot be used for I&I analysis.

3.3.6 GIS Data

As part of the flow meter data analysis in Sliicer, the calculated flow components were divided by various drainage area characteristics such as length of sewer and surface area. The resulting unit flows were compared based on these characteristics in order to normalize the flows. A list of the GIS data sets used in the Sliicer calculations is provided in Table 3-1.

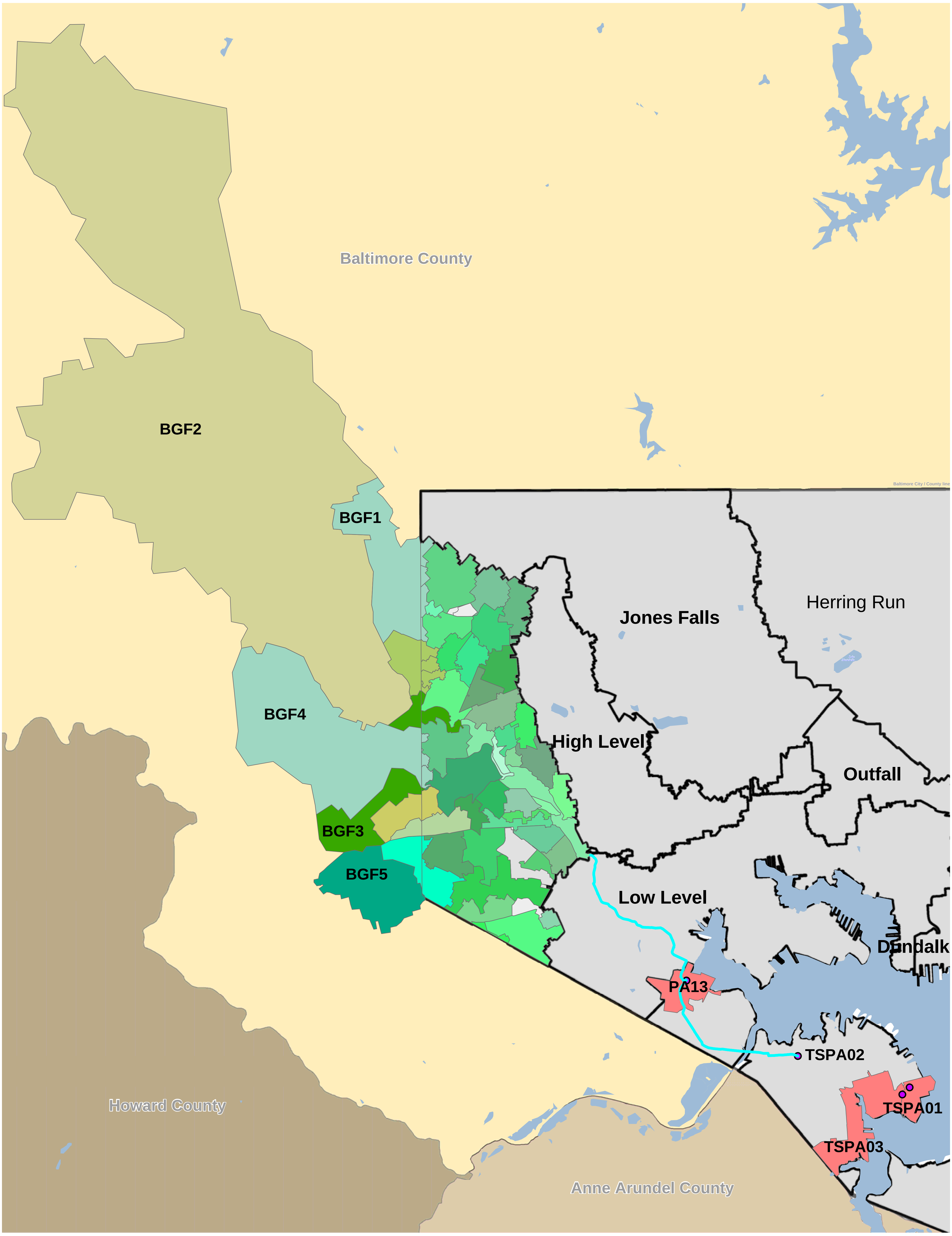
3.4 Flow Meter Data Analysis Criteria

3.4.1 Calculation of Wastewater Components

Flow in the sanitary sewer collection system consists of three basic components:

A. Sewage - Wastewater flows from residences and businesses.

B. Base Infiltration - Groundwater infiltration entering the collection system through sewer defects (e.g. leaking joints, cracks, voids, etc.). Base



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0 4,000 8,000 Feet

1 inch equals 8,000 feet

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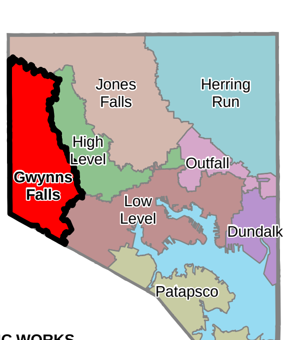

LEGEND

- GWYNNS FALLS FLOW METER BASINS
- PATAPSCO FLOW METER BASINS
- BALTIMORE COUNTY
- BALTIMORE CITY

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Figure 3-2

Full Extents of Gwynns Falls Sewershed

Table 3-1
Sliicer Analysis GIS Data Set Summary

FLOW METER SITE	LENGTH OF SEWER (LF)	LENGTH-SIZE OF SEWER (inch-diameter-mile)	DRAINAGE AREA (acres)
GF01A	60,582	104.47	320.65
GF01B	6,102	10.65	44.12
GF02	64,685	119.12	416.49
GF03	28,270	46.29	166.57
GF05	28,017	47.55	258.18
GF06	47,589	81.49	379.37
GF07	34,754	54.06	252.25
GF08	21,400	38.99	119.87
GF09	21,938	36.09	70.11
GF10	31,819	51.51	144.90
GF11	25,825	41.15	105.38
GF12	2,956	6.67	33.19
GF13	50,935	117.55	113.97
GF13A	N/A	N/A	N/A
GF14	43,416	79.48	182.24
GF15	31,768	48.87	135.10
GF16	5,131	7.48	40.21
GF17	13,336	20.37	126.15
GF18	15,600	25.30	99.66
GF19	34,386	53.29	216.97
GF20	40,916	64.27	304.73
GF21	13,912	21.19	77.98
GF22	44,903	68.90	215.94
GF23	22,856	33.41	285.28
GF24	26,417	55.96	247.47
GF25	17,416	31.80	135.76
GF26	46,330	83.60	193.00
GF27	34,077	56.50	158.19
GF28	19,905	31.72	117.41
GF29	69,946	147.03	371.54
GF30	29,072	62.52	193.81
GF31	56,987	97.16	421.72
GF32	34,783	59.20	213.27
GF33	46,953	76.98	197.14
GF34	75,064	121.46	195.42
GFDR1+GFDR2	23,903	81.60	416.83
GFS13	18,860	29.50	113.81
GFS14	11,863	17.92	51.04
GFS26	N/A	N/A	N/A
TSGF01	4,927	12.40	29.27
TSGF02	30,275	160.71	185.19
TSGF03 + TSGF04 + GF13A + GFS26	21,592	441.59	421.93
City Sewershed Total:	**1,259,467**	**2,745.80**	**7,772.14**
*BGF1	166,576	281.88	1,285.39
*BGF2	1,798,758	3,890.29	20,370.24
*BGF3	79,106	130.98	598.24
*BGF4	208,143	408.65	2,896.55
*BGF5	121,376	188.93	904.24
*PA13	29,650	113.75	282.96
*TSPA01	1,864	32.27	3.82
*TSPA02	125,917	700.40	6.89
*TSPA03	15,203	154.74	587.46

Notes:

*Other Drainage Basins- These meters are either Border Flow Meters or Flow Meters not in the Gwynns Falls Drainage Basin.

1. GFDR1 & GFDR2, GF13A, GFS26 and TSGF03 & TSGF04 are flow meter pairs on parallel sewers that share a common drainage area. The sum of each added together represents the total to the site.

2. The Length of Sewer and Length-Size of Sewer for Flow Meters BGF1, BGF3, BGF4, TSGF02, GF06, GF19, GF20, GF29 include data for the portion of drainage area extending into Baltimore County and the portion within Baltimore City.

infiltration typically occurs where the collection system is located below the water table. As directed by the City, the Stevens / Schutzbach calculation was used to determine Base Infiltration.

C. Rainfall-Dependent Infiltration and Inflow (RDII) - Rain water entering the sewer collection system through illegal/illicit storm drain connections and other sources that convey rainwater directly into the collection system. Rainfall that enters the sewer system by rapid infiltration falls under this category for the purposes of flow meter data analysis.

The RDII component is based on the relationship between rainfall and the RDII response recorded at a flow meter. For comparison between flow meter and industry standards, each flow meter's RDII value was calculated for a 2-year 24-hour storm event.

The Base Infiltration and RDII components differ in their flow characteristics and cause. Base Infiltration flow rates change slowly over time since they are directly related to groundwater levels. Rainfall-Dependent Infiltration and Inflow flow rates change quickly over time since they are directly related to rainfall rates and quantities.

3.4.2 Global Settings

Default Sliicer global settings were set to simplify the flow meter data analysis process. The global settings were customized to increase or decrease the number of dry days and number of storm events used in the analysis and the storm event start and end times. Typically the study start and end dates corresponded to the first and last day of available data, respectively.

Step lengths were a global function that could be set to the user's preference. By default, Sliicer set the study step length to 60 minutes although Sliicer could calculate step lengths ranging from 5 to 1,440 minutes (1 day). Shorter step lengths required longer calculation time but produced more refined graphs. Time steps of 30 minutes were used for the sewershed project.

Dry day customization was another global option. The Sliicer program followed two rules to determine a "dry" day:

A. Verified that the daily precipitation had not exceeded a certain limit (refer to Section 3 of the BaSES Manual for the limit derivation).

B. Confirmed that the daily flow rate for each day was within a certain percentage (+/-) of the cumulative average daily flow rate for the days that had been previously calculated.

Days that did not meet the above criteria were excluded from the dry day calculations.

The Sliicer program provided for three wet weather or storms event customizations:

A. "Time Lapse" represented the time elapsed after rainfall had stopped during which a flow meter still experienced the RDII effects of the rainfall event.

B. "Rain Threshold" represented the minimum rain amount that fell in an area for a rainfall event to be recognized as a rain event.

C. “Dribble” represented the rainfall amount that did not meet the Rain Event criteria but was still recorded.

Units were also customizable in Sliicer as a global option for input and output data.

3.4.3 Dry Day Data Selection

The typical diurnal flows for a given site during non-rainfall event days were based on the dry day selection process. For a procedural explanation of the process, refer to Chapter 5 of the Sliicer User’s Manual and Section 3 of the BaSES Manual.

Sliicer automatically selected the dry days for each season based upon the global setting parameters. The parameter settings used in the analysis were:

A. Every day of flow meter data that did not include rainfall data.

B. Every day with a daily flow rate that was within +/- 15 percent of the dry day average.

Dry days automatically selected by Sliicer using the global parameters were plotted versus the dry day average curve. The resulting graph presented all of the dry days included in the calculation compared to the average. Days that did not conform to the average pattern were identified for manual removal from the dry day data set.

In the event that a season had zero dry days that were determined usable by the Sliicer global parameters or by user analysis, the season was turned off and the similar season from a different year was used. For example, if Summer 2006 data for a particular site had no usable Weekend Dry Days, the Weekend Dry Days from Summer 2007 were used in place of 2006.

3.4.4 Wet Weather Data Selection

The global rainfall events were selected by the City and are listed in Table 3-2. For a procedural explanation of the wet weather data selection process, refer to Chapter 5 of the Sliicer User’s Manual and Section 3 of the BaSES Manual. Similar to Dry Day Data Selection, Sliicer automatically set default wet weather analysis settings based on the global parameters which were identified in the BaSES Manual.

Table 3-2
Global Rainfall Events

Rain Event	Rain Event Start Date/Time		Rain Event End Date/Time	
1	5/11/2006	12:00	5/11/2006	22:00
2	5/14/2006	23:00	5/15/2006	16:00
3	6/2/2006	19:00	6/3/2006	6:00
4	6/19/2006	14:00	6/19/2006	16:00
5	6/24/2006	13:00	6/24/2006	22:00
6	6/25/2006	4:00	6/26/2006	22:00
7	7/5/2006	11:00	7/6/2006	6:00
8	7/22/2006	14:00	7/23/2006	0:00
9	9/1/2006	6:00	9/2/2006	17:00
10	9/5/2006	2:00	9/5/2006	17:00
11	9/14/2006	1:00	9/14/2006	21:00
12	9/28/2006	17:00	9/28/2006	22:00
13	10/5/2006	20:00	10/6/2006	16:00
14	10/17/2006	7:00	10/18/2006	2:00
15	10/19/2006	20:00	10/20/2006	11:00
16	10/27/2006	15:00	10/28/2006	8:00
17	11/7/2006	20:00	11/8/2006	15:00
18	11/16/2006	8:00	11/16/2006	17:00
19	11/22/2006	11:00	11/23/2006	3:00
20	12/22/2006	12:00	12/23/2006	3:00
21	12/25/2006	12:00	12/26/2006	1:00
22	12/31/2006	16:00	1/1/2007	14:00
23	1/7/2007	17:00	1/8/2007	16:00
24	3/1/2007	18:00	3/2/2007	9:00
25	3/15/2007	16:00	3/16/2007	17:00
26	3/23/2007	13:00	3/24/2007	10:00
27	4/4/2007	3:00	4/4/2007	9:00
28	4/11/2007	21:00	4/12/2007	6:00
29	4/14/2007	19:00	4/16/2007	3:00

Each rainfall event for every flow meter was reviewed as part of the analysis. Default parameters were modified on an event-specific basis to match the recorded and predicted dry weather diurnal pattern prior to the start of the rainfall event so that the RDII response could be identified. The predicted flow rates were based on the dry day flow diurnal patterns.

The Sliicer program identified four periods for each rainfall event:

A. Precomp - the period leading up to rainfall event, typically 24 hours.

B. Storm – The period of actual rainfall.

C. Recovery 1 - The period immediately after rainfall.

D. Recovery 2 - The period after rainfall when RDII continued to enter the system but was decreasing.

The Precomp value was reviewed with the intent of modifying it from the default setting if it produced a more accurate relationship between recorded flow meter data prior to the rainfall and the predicted diurnal pattern. As a general industry standard, precomp values that differ from the dry day average by more than +/- 15 percent may require an adjustment. Rainfall events that could not be adjusted to produce an acceptable relationship between the recorded flow meter data prior to the rainfall and the predicted diurnal pattern were excluded from the analysis process.

The RDII calculated in wet weather analysis is the volume recorded during the storm period only and does not include volumes from the recovery periods.

The consistency of RDII response to each rainfall events was also considered in the wet weather analysis process. Those events that produced unreasonable RDII responses compared to the amount of rainfall associated with the event were excluded from the analysis. For example, a major rainfall event that produced little or no RDII at a site that typically experienced significant RDII response to moderate sized rainfalls would be excluded from the analysis.

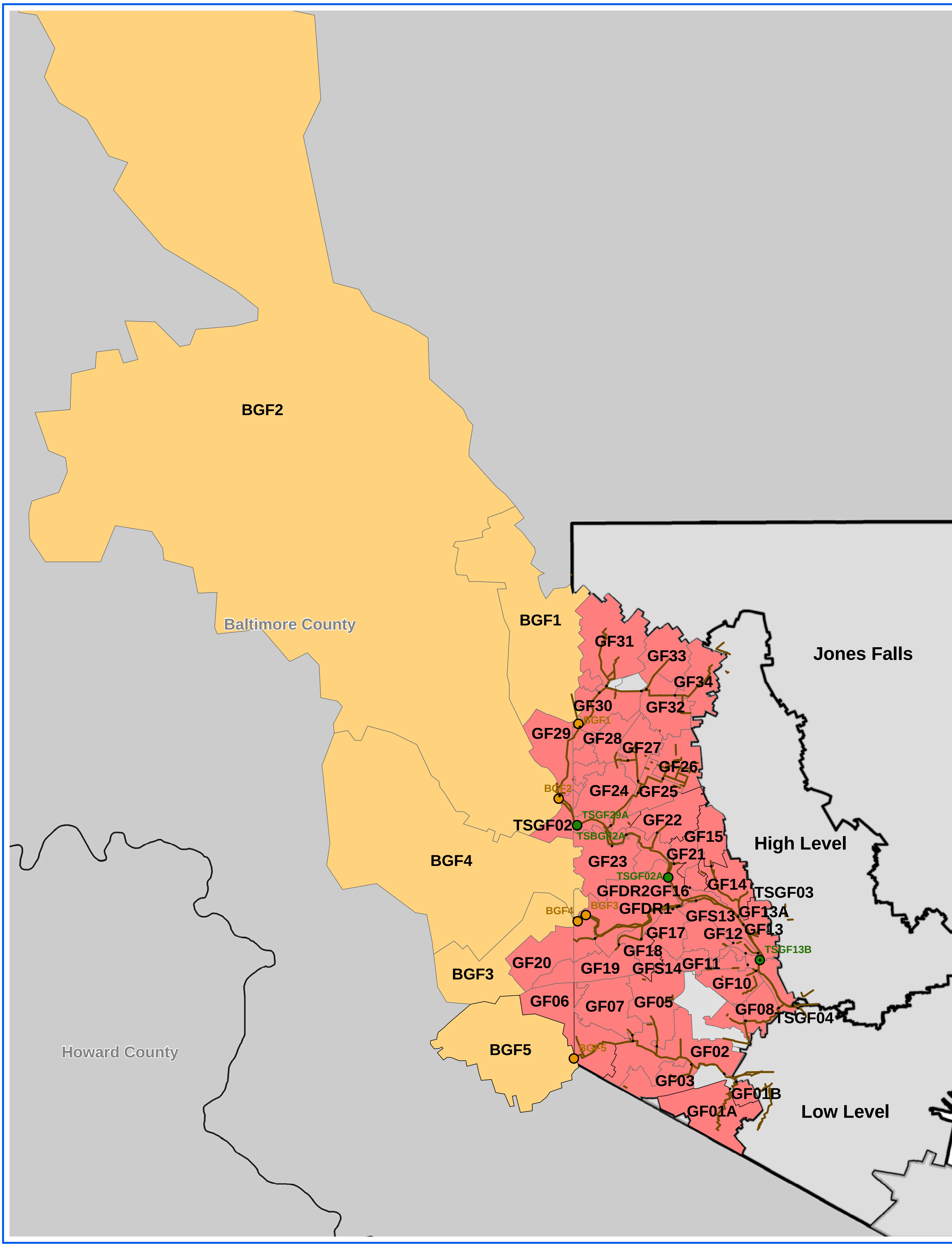
Wet weather events that occurred during periods of inferred data were not used in the data analysis.

3.5 Flow Meter Data Summary

Flow Meter Site Hydrographs for all flow meters are presented in Appendix 3-1 – Flow Meter Hydrographs. Scatter Graphs for all flow meters are presented in Appendix 3-2 – Flow Meter Scatter Graphs. Table 3-3 – Flow Meter Sites Excluded from Analysis identifies flow meter sites excluded from the analysis due to their flows being from outside the Gwynns Falls sewershed. These are shown graphically in Figure 3-3.

Table 3-3
Flow Meter Sites Excluded from I&I Assessment

Flow Meter Site
BGF1
BGF2
BGF3
BGF4
BGF5
TSPA01
TSPA02
TSPA03



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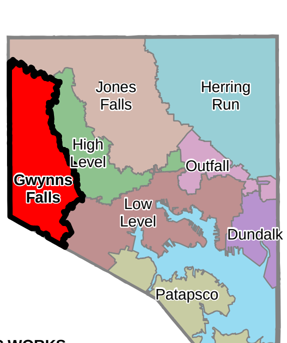
1 inch equals 6,000 feet



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- BORDER FLOW METER
- SUPPLEMENTAL FLOW METER
- I&I FLOW METER DRAINAGE BASIN
- BORDER FLOW METER DRAINAGE BASIN

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Department of Public Works
Project No. 1032
Gwynns Falls Sanitary Sewer Evaluation Study
August 2008
Figure 3-3
Flow Meter Drainage Basins
I&I and Border Flow Meters

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4.0 Analysis Results

The tables included in this chapter cover only those flow meter sites that were included in the inflow and infiltration analysis flow meter drainage areas (reference Section 3.5) as indicated in Figure 3-3.

4.1 Wastewater Flow Components

A summary of flow components (Sewage, Base Infiltration, and Rainfall-Dependent Infiltration & Inflow) by flow meter drainage area is provided in Table 4-1. As expected, most sites conformed to the following flow rate calculation:

$$\text{Net Average Daily Flow Rate} = \text{Net Average Wastewater Flow Rate} + \text{Net Average Base Infiltration}$$

However, the Sliicer analysis produced negative Wastewater or Base Infiltration values at several sites, which were replaced with zeroes. Single occurrences of negative values or unreasonably high values are shaded in yellow in Table 4-1. Sites that exhibited overall questionable data are shaded green.

Note that the Daily Minimum Flow Rate and Daily Maximum Flow Rate values are instantaneous minimum or maximum values, not average daily totals. Additionally, the calculated RDII volume is the total inflow volumetric response to the design rainfall event, not a flow rate. The RDII volume applied to a rate curve would produce a significantly higher instantaneous peak flow rate.

4.2 Assessment of Flow Components

Table 4-2 normalizes the flow components by independent criteria such as sewer length, sewer length per size and drainage area to compare the flows between each other and to typical industry benchmark values. The benchmark value does not represent an absolute threshold but is a reference point for comparison. Some comparisons indicate that most sites exceed the benchmark value in which case an overall ranking would produce a more useful comparison.

Shaded sites or values in Table 4-2 appear to be invalid but cannot be explained based on the available information. Sites shaded in green indicate flow meters with poor overall data quality over the entire flow monitoring period. Sites shaded in yellow indicate specific comparison values that are beyond reasonably expected values.

The values at the bottom of Table 4-2 represent the total flow for the sewershed divided by the total of the individual criteria. For example, the average wastewater flow by linear foot of 9.57 gallons per day per linear foot (gpd/LF) is calculated by summing the total sewershed sewage flow rate (12.047 mgd) and dividing by the total sewershed sewer length (1,259,467 LF).

Table 4-1
Flow Meter Drainage Area Flow Components

	Dry Weather Data		Net Average Daily Flow Rate Diurnal Patterns			Rainfall-Dependent Infiltration & Inflow (RDII) Response to 2-Yr 24-Hr Rainfall Event	
Sliicer Term	NetWasteWater	NetBaseInfil	NetDiurnalPeak	NetDiurnalMin	NetDiurnalAverage	N/A	N/A
Flow Meter	**Net Average Waste Water**	**Net Average Base Infiltration**	**Net Average Daily Maximum Flow Rate**	**Net Average Daily Minimum Flow Rate**	**Net Average Daily Flow Rate**	**Net RDII Volume**	**Net Total Design Flow Rate**
Units	**(mgd)**	**(mgd)**	**(mgd)**	**(mgd)**	**(mgd)**	**(million gallons)**	**(mgd)**
GF01A	0.002	0.007	0.011	0.007	0.009	0.120	0.129
GF01B	0.335	0.221	0.734	0.321	0.556	0.747	1.303
GF02	1.126	0.204	1.677	0.923	1.331	3.678	5.008
GF03	0.274	0.261	0.733	0.353	0.535	1.068	1.604
GF05	0.119	0.149	0.338	0.181	0.268	0.663	0.931
GF06	0.280	0.483	0.986	0.669	0.763	1.421	2.184
GF07	0.097	0.084	0.268	0.104	0.181	1.540	1.721
GF08	0.143	0.010	0.254	0.054	0.154	0.564	0.717
GF09	0.126	0.242	0.420	0.286	0.369	0.900	1.269
GF10	0.155	0.307	0.542	0.365	0.461	0.838	1.299
GF11	0.157	0.208	0.422	0.258	0.365	0.542	0.906
GF12	0.022	0.032	0.105	0.036	0.054	0.266	0.320
GF13	0.461	0.707	1.780	0.396	1.169	6.056	7.225
GF13A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GF14	0.000	0.047	0.054	0.002	0.017	0.450	0.496
GF15	0.157	0.220	0.448	0.270	0.377	1.063	1.440
GF16	0.007	0.020	0.033	0.020	0.027	0.526	0.552
GF17	0.087	0.164	0.285	0.189	0.251	0.413	0.664
GF18	0.046	0.098	0.192	0.068	0.145	0.386	0.530
GF19	0.205	0.236	0.565	0.304	0.442	2.766	3.207
GF20	0.244	0.305	0.706	0.395	0.550	0.740	1.290
GF21	0.065	0.095	0.205	0.110	0.161	0.356	0.516
GF22	0.304	0.446	0.886	0.566	0.749	2.715	3.465
GF23	0.176	0.191	0.457	0.244	0.367	0.347	0.714
GF24	0.000	0.289	0.315	0.199	0.246	0.658	0.948
GF25	0.033	0.021	0.095	0.024	0.061	2.658	2.712
GF26	0.164	0.229	0.467	0.283	0.393	2.012	2.405
GF27	0.158	0.105	0.321	0.160	0.263	1.205	1.468
GF28	0.071	0.151	0.264	0.171	0.221	0.790	1.011
GF29	0.318	0.071	0.540	0.265	0.389	1.026	1.415
GF30	0.192	0.000	0.222	0.000	0.125	2.493	2.685
GF31	0.363	0.252	0.808	0.367	0.615	1.729	2.344
GF32	0.049	0.260	0.441	0.211	0.310	0.371	0.680
GF33	0.296	0.192	0.649	0.275	0.488	1.670	2.158
GF34	0.231	0.265	0.592	0.345	0.497	2.589	3.086
GFDR1 & GFDR2	1.115	0.210	1.410	1.054	1.325	0.000	1.325
GFS13	0.110	0.158	0.343	0.189	0.268	0.346	0.614
GFS14	0.071	0.063	0.171	0.075	0.135	0.641	0.776
GFS26	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TSGF01	0.350	0.090	0.564	0.314	0.440	1.596	2.036
TSGF02	3.895	0.443	6.036	1.710	4.349	21.835	26.173
TSGF03 & TSGF04	0.000	7.333	0.819	4.536	3.228	0.000	7.333
PA13	0.041	0.065	0.138	0.073	0.107	0.082	0.188
Total:	**12.047**	**14.938**	**26.296**	**16.373**	**22.761**	**69.865**	**96.851**
BGF1	0.634	0.659	1.563	0.959	1.294	3.277	4.571
BGF2	10.040	2.850	17.313	6.978	12.891	52.465	65.356
BGF3	0.687	0.376	1.336	0.616	1.063	4.915	5.977
BGF4	2.109	1.779	4.523	3.036	3.888	6.200	10.089
BGF5	0.416	0.380	1.017	0.540	0.796	1.926	2.722
TSPA01	7.148	2.187	15.554	1.951	9.770	38.165	47.500
TSPA02	11.642	0.517	19.406	1.652	12.293	78.649	90.808
TSPA03	3.705	2.627	7.421	4.945	6.332	10.082	16.414

Represents Sites with Overall Poor Data Quality
Represents Site Specific Values that appear to be Invalid/Irregular

Note: GF13 and GFS26 were flow meter sites located on one leg of a parallel sewer with no corresponding flow meter on the other leg(s). Therefore, the total flow rate could not be calculated, making these sites useless. GF13 was also one one leg of a parallel sewer without a corresponding flow meter on the other leg. However, GF13A was located upstream of it on the same leg. Therefore, GF13 could be used to calculate net flows only.

Table 4-2
Flow Comparisons Summary Table

	Waste Water (Sewage Only)				Base Infiltration				RDII Response to 2-yr 24-hr Rain Event				RDII and Base Infiltration (I&I)		
Flow Meter	Net Waste Water Per Linear Foot	Net Waste Water per Inch-Dia-Mile	Net Waste Water per Acre	Net Waste Water % of Net Dry Weather Average Daily Flow Rate	Net Base Infiltration Per Linear Foot	Net Base Infiltration Per Inch-Dia-Mile	Net Base Infiltration Per Acre	Net Base Infiltration % of Net Dry Weather Average Daily Flow Rate	Net RDII Response Per Linear Foot	Net RDII Response Per Inch-Dia-Mile	Net RDII Response Per Acre	"Capture Coefficient" % of Rainfall Entering as Net RDII Response	Net I&I Per Linear Foot	Net I&I Per Inch-Dia-Mile	Net I&I Per Acre
Units	(gpd/LF)	(gpd/in-dia-mi)	(gpd/acre)	(%)	(gpd/LF)	(gpd/in-dia-mi)	(gpd/acre)	(%)	(gpd/LF)	(gpd/in-dia-mi)	(gpd/acre)	(%)	(gpd/LF)	(gpd/in-dia-mi)	(gpd/acre)
GF01A	0.04	20	7	22.77%	0.12	69	23	77.23%	1.97	1,145	373	0.43%	2.09	1,214	396
GF01B	54.84	31,404	7,583	60.19%	36.27	20,771	5,015	39.81%	122.41	70,106	16,928	19.35%	158.68	90,876	21,944
GF02	17.41	9,457	2,705	84.66%	3.15	1,713	490	15.34%	56.86	30,874	8,830	10.09%	60.01	32,587	9,320
GF03	9.70	5,922	1,646	51.20%	9.24	5,646	1,569	48.80%	37.79	23,080	6,414	7.33%	47.04	28,726	7,983
GF05	4.25	2,506	462	44.40%	5.33	3,138	578	55.60%	23.66	13,940	2,568	2.93%	28.99	17,078	3,146
GF06	5.89	3,440	739	36.73%	10.15	5,926	1,273	63.27%	29.86	17,436	3,745	4.28%	40.00	23,362	5,018
GF07	2.78	1,790	384	53.48%	2.42	1,558	334	46.52%	44.32	28,491	6,106	6.98%	46.74	30,049	6,440
GF08	6.69	3,672	1,194	93.22%	0.49	267	87	6.78%	26.34	14,458	4,703	5.38%	26.83	14,725	4,789
GF09	5.77	3,505	1,804	34.29%	11.05	6,718	3,458	65.71%	41.02	24,933	12,833	14.67%	52.07	31,651	16,291
GF10	4.86	3,002	1,067	33.51%	9.64	5,958	2,118	66.49%	26.33	16,268	5,783	6.61%	35.98	22,226	7,901
GF11	6.08	3,813	1,489	43.01%	8.05	5,053	1,973	56.99%	20.97	13,163	5,140	5.87%	29.02	18,216	7,113
GF12	7.37	3,267	657	40.84%	10.68	4,731	951	59.16%	90.07	39,901	8,022	9.17%	100.75	44,632	8,973
GF13	9.06	3,926	4,049	39.48%	13.89	6,017	6,206	60.52%	118.90	51,521	53,140	60.74%	132.78	57,538	59,346
GF13A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GF14	0.00	0	0	0.00%	1.07	586	255	100.00%	10.36	5,660	2,468	2.82%	11.43	6,245	2,724
GF15	4.95	3,219	1,164	41.74%	6.91	4,494	1,626	58.26%	33.47	21,755	7,870	9.00%	40.38	26,249	9,496
GF16	1.35	926	172	25.89%	3.86	2,649	493	74.11%	102.45	70,296	13,071	14.94%	106.31	72,945	13,564
GF17	6.55	4,288	692	34.77%	12.29	8,045	1,299	65.23%	30.99	20,287	3,276	3.74%	43.27	28,332	4,575
GF18	2.97	1,831	465	32.16%	6.26	3,862	980	67.84%	24.75	15,263	3,874	4.43%	31.01	19,124	4,854
GF19	5.98	3,856	947	46.51%	6.87	4,434	1,089	53.49%	80.43	51,902	12,746	14.57%	87.30	56,336	13,835
GF20	5.97	3,803	802	44.47%	7.46	4,748	1,001	55.53%	18.10	11,521	2,430	2.78%	25.56	16,269	3,431
GF21	4.69	3,079	837	40.65%	6.85	4,496	1,222	59.35%	25.57	16,785	4,561	5.21%	32.42	21,280	5,783
GF22	6.77	4,410	1,407	40.54%	9.92	6,467	2,063	59.46%	60.47	39,411	12,575	14.37%	70.40	45,878	14,638
GF23	7.69	5,261	616	47.90%	8.37	5,723	670	52.10%	15.20	10,396	1,218	1.39%	23.56	16,119	1,888
GF24	0.00	0	0	0.00%	10.95	5,167	1,168	100.00%	24.92	11,766	2,661	3.04%	35.87	16,933	3,829
GF25	1.87	1,023	240	60.25%	1.23	675	158	39.75%	152.59	83,566	19,575	22.37%	153.82	84,241	19,733
GF26	3.53	1,956	847	41.61%	4.95	2,744	1,189	58.39%	43.43	24,069	10,426	11.92%	48.38	26,813	11,615
GF27	4.63	2,795	998	59.98%	3.09	1,865	666	40.02%	35.36	21,327	7,617	8.71%	38.45	23,191	8,283
GF28	3.55	2,228	602	31.93%	7.57	4,749	1,283	68.07%	39.69	24,900	6,728	7.69%	47.25	29,650	8,011
GF29	4.54	2,162	856	81.73%	1.02	483	191	18.27%	14.67	6,980	2,762	3.16%	15.69	7,463	2,954
GF30	6.61	3,073	991	100.00%	0.00	0	0	0.00%	85.74	39,872	12,862	14.70%	85.74	39,872	12,862
GF31	6.37	3,734	860	58.98%	4.43	2,597	598	41.02%	30.34	17,797	4,100	4.69%	34.77	20,394	4,699
GF32	1.42	835	232	15.96%	7.48	4,397	1,220	84.04%	10.66	6,261	1,738	1.99%	18.14	10,658	2,958
GF33	6.30	3,844	1,501	60.65%	4.09	2,494	974	39.35%	35.57	21,694	8,471	9.68%	39.66	24,188	9,445
GF34	3.08	1,905	1,184	46.58%	3.53	2,184	1,358	53.42%	34.50	21,319	13,251	15.15%	38.03	23,503	14,609
GFDR1 & GFDR2	46.66	13,666	2,675	84.16%	8.78	2,573	504	15.84%	0.00	0	0	3.70%	8.78	2,573	504
GFS13	5.82	3,718	964	40.91%	8.40	5,370	1,392	59.09%	18.33	11,719	3,038	3.47%	26.73	17,090	4,430
GFS14	6.02	3,983	1,399	52.99%	5.34	3,533	1,241	47.01%	54.05	35,779	12,564	14.36%	59.39	39,312	13,805
GFS26	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TSGF01	71.03	28,211	11,956	79.54%	18.27	7,257	3,076	20.46%	323.96	128,675	54,531	62.33%	342.23	135,932	57,607
TSGF02	128.66	24,238	21,034	89.78%	14.64	2,758	2,394	10.22%	721.20	135,868	117,904	100.00%	735.84	138,626	120,298
TSGF03 & TSGF04	0.00	0	0	0.00%	339.62	16,606	17,380	100.00%	0.00	0	0	7.80%	339.62	16,606	17,380
PA13	1.38	361	145	38.54%	2.21	576	231	61.46%	2.75	718	288	0.33%	4.96	1,293	520
CITY SEWERSHED AVERGE	**9.57**	**4,388**	**1,550**	**44.64%**	**11.86**	**5,440**	**1,922**	**55.36%**	**55.47**	**25,444**	**8,989**	**10.27%**	**67.33**	**30,885**	**10,911**
BGF1	3.81	2,251	494	49.04%	3.96	2,339	513	50.96%	19.67	11,626	2,549	2.91%	23.63	13,964	3,062
BGF2	5.58	2,581	493	77.89%	1.58	733	140	22.11%	29.17	13,486	2,576	2.94%	30.75	14,219	2,715
BGF3	8.69	5,246	1,148	64.65%	4.75	2,869	628	35.35%	62.13	37,523	8,215	9.39%	66.88	40,391	8,843
BGF4	10.13	5,161	728	54.24%	8.55	4,354	614	45.76%	29.79	15,173	2,141	2.45%	38.34	19,527	2,755
BGF5	3.42	2,200	460	52.24%	3.13	2,011	420	47.76%	15.87	10,196	2,130	2.43%	19.00	12,207	2,550
TSPA01	3,833.82	221,466	1,871,864	76.57%	1,173.17	67,770	572,798	23.43%	20,470.60	1,182,515	9,994,772	100.00%	21,643.77	1,250,285	10,567,570
TSPA02	92.46	16,622	1,689,803	95.75%	4.11	738	75,057	4.25%	624.61	112,291	11,415,682	100.00%	628.71	113,030	11,490,739
TSPA03	243.73	23,946	6,308	58.52%	172.78	16,976	4,472	41.48%	663.14	65,153	17,162	19.62%	835.92	82,129	21,634

Represents Sites with Overall Poor Data Quality

Represents Site Specific Values that appear to be Invalid/Irregular

4.2.1 Sewage Flow

The portion of flow comprised entirely of wastewater (excluding Base Infiltration and Rainfall-Dependent Infiltration & Inflow) is referred to as Sewage Flow. For flow meter site comparisons based on sewage flow, refer to the Sewage Flow section of Table 4-2. A typical industry benchmark or threshold value of 5 gallons per day per linear foot (gpd/lf) is assumed for comparison purposes.

4.2.2 Base Infiltration

The portion of flow comprised entirely of Base Infiltration was calculated using the Stevens / Schutzbach method as directed by the City. For flow meter site comparisons based on Base Infiltration, refer to the Base Infiltration section of Table 4-2.

Base Infiltration Benchmark Values

30,000 gpd/mile (equates to 5.68 gpd/LF)
2,000 gpd/inch-diameter-mile
1,000 gpd/acre

4.2.3 Rainfall-Dependent Infiltration & Inflow (RDII)

For comparisons between sites based solely on RDII, refer to the RDII section of Table 4-2, which also includes comparisons to typical industry benchmark threshold values.

To normalize each flow meter basin in terms of RDII, the RDII value for each site represents the total RDII flow that can be anticipated in response to a 2-year 24-hour rainfall event based on each individual site's rainfall-to-RDII relationship using IDF (Intensity – Duration – Frequency) tables and curves specific to the City of Baltimore as contained in Sliicer. As provided in Sliicer, the IDF curve for a 2-year 24-hour rainfall event produces a rainfall of 3.22 inches; the RDII volume (in millions of gallons) in Table 4-1 is in response to this rainfall.

The capture coefficient represents the fraction of rainfall that enters the sanitary sewer as RDII and is used to normalize RDII by rainfall and area. Using Q vs. I data from Sliicer to calculate the RDII response to a 2-year 24 hour rainfall event and dividing it by the total volume of rainfall that fell on each flow meter drainage basin for the storm event generates the capture coefficient:

Calculated RDII Response = (Q vs. I Slope) x [(3.22 inches of Rain) + y-intercept]

Rainfall Gallons per Basin = (Basin Acres) x (43,560 SF / acre) x (3.22 in Rainfall) x (ft / 12 in) x (7.485 gal/cf)

Capture Coefficient = (Calculated RDII Response) / (Rainfall Gallons per Basin)

The capture coefficient is provided in Table 4-2. A typical industry benchmark or threshold value of 1.00 % capture coefficient is assumed for comparison purposes.

4.3 Ranking Flow Meter Basins by Base Infiltration and Rainfall-Dependent Infiltration & Inflow (RDII) by Length

Table 4-3 ranks flow meter drainage basin RDII by length of sewer in accordance with the BaSES manual. It should be noted that the sewer length values used in the calculations are based on information provided in the GIS, which, as currently exists, contains some discrepancies.

The gpd/LF values were reviewed to identify distinct groupings or ranges of similar data values. Using this approach, there is a significant increase between the sites ranked 9 and 10, which equates to a threshold value of 50 gpd/LF. However, there are six sites that produced unreasonable results that were not included in the rankings. Three sites produced extremely high values and the other three sites produced extremely low values. If the GIS can be updated further, these areas may be able to produce more reasonable results.

Based on the flow meter data and analysis in Sliicer and the sewer length data available, it is recommended that the nine sites with the highest gpd/LF value listed in Table 4-3 (those with values greater than 50 gpd/LF) be considered for smoke testing. It is further recommended that CCTV inspections, if available, be reviewed to develop the smoke testing plan.

4.4 Flows by Branch

Flow totals by individual branch interceptors are presented in Table 4-4 and compared to drainage area characteristics in Table 4-5. Figure 4-1 identifies the drainage area attributed to each branch.

The sewershed totals at the bottom of Table 4-4 exclude flows from the drainage areas in Baltimore County. The total flows by branch (reference Table 4-4) result in somewhat different flow component totals than the sum of the individual flow meter drainage areas (Table 4-1). The wastewater (sewage) component is approximately 10% lower than the total from Table 4-1, the Base Infiltration is approximately 14% higher than the total from Table 4-1, and the RDII is approximately 92% lower than the total from Table 4-1. The RDII total is significantly lower due to the difference between the calculation methodologies used. In Table 4-1, the RDII total represents the summation of the individual net RDII values for each flow meter, whereas in Table 4-4, the "Sewershed Total" is calculated by adding the gross flows at the bottom of the branch. There are multiple factors that may contribute to the difference in flows which are discussed in Section 4.5.

Assessed by branch, as shown in Table 4-5, no single branch appears to experience significantly higher I&I than the rest.

4.5 Flows by Sewershed

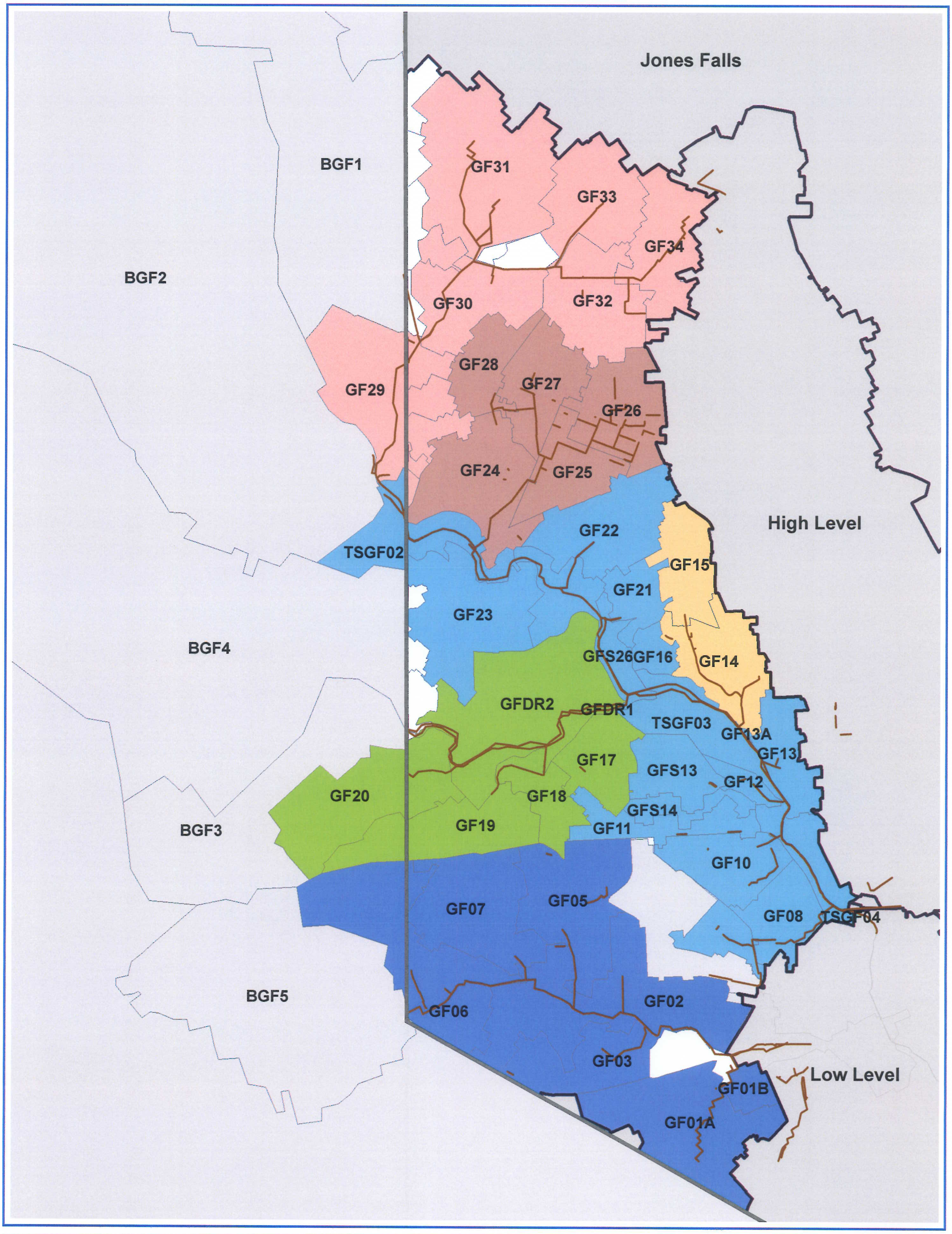
For the purpose of assessing the sewershed as a whole, focusing solely on the Gwynns Falls drainage area within the City limits and excluding the Southwest Diversion, the total is the sum of the Gwynns Falls Interceptor (TSGF03 and TSGF04) and the Maiden's Choice Interceptor (GF02). In order to calculate the total from the City portion alone, the five border flow meters (BGF1, BGF2, BGF3, BGF4, and BGF5) are subtracted out which removes the majority of flow from Baltimore County.

Table 4-3
RDII Ranking by Length

Flow Meter	Net RDII Response Per Linear Foot	Overall Ranking*
GF01A	1.97	N/A
GF01B	122.41	N/A
GF02	56.86	8
GF03	37.79	14
GF05	23.66	27
GF06	29.86	21
GF07	44.32	10
GF08	26.34	22
GF09	41.02	12
GF10	26.33	23
GF11	20.97	28
GF12	90.07	4
GF13	118.90	2
GF13A	N/A	N/A
GF14	10.36	34
GF15	33.47	18
GF16	102.45	3
GF17	30.99	19
GF18	24.75	26
GF19	80.43	6
GF20	18.10	30
GF21	25.57	24
GF22	60.47	7
GF23	15.20	31
GF24	24.92	25
GF25	152.59	1
GF26	43.43	11
GF27	35.36	16
GF28	39.69	13
GF29	14.67	32
GF30	85.74	5
GF31	30.34	20
GF32	10.66	33
GF33	35.57	15
GF34	34.50	17
GFDR1 & GFDR2	0.00	N/A
GFS13	18.33	29
GFS14	54.05	9
GFS26	N/A	N/A
PA13	2.75	35
TSGF01	323.96	N/A
TSGF02	721.20	N/A
TSGF03 & TSGF04	0.00	N/A

Flow Meter	Net I&I Per Linear Foot	Overall Ranking*
GF25	152.59	1
GF13	118.90	2
GF16	102.45	3
GF12	90.07	4
GF30	85.74	5
GF19	80.43	6
GF22	60.47	7
GF02	56.86	8
GFS14	54.05	9
GF07	44.32	10
GF26	43.43	11
GF09	41.02	12
GF28	39.69	13
GF03	37.79	14
GF33	35.57	15
GF27	35.36	16
GF34	34.50	17
GF15	33.47	18
GF17	30.99	19
GF31	30.34	20
GF06	29.86	21
GF08	26.34	22
GF10	26.33	23
GF21	25.57	24
GF24	24.92	25
GF18	24.75	26
GF05	23.66	27
GF11	20.97	28
GFS13	18.33	29
GF20	18.10	30
GF23	15.20	31
GF29	14.67	32
GF32	10.66	33
GF14	10.36	34
PA13	2.75	35
GF01A	1.97	N/A
GF01B	122.41	N/A
GFDR1 & GFDR2	0.00	N/A
TSGF01	323.96	N/A
TSGF02	721.20	N/A
TSGF03 & TSGF04	0.00	N/A
GF13A	N/A	N/A
GFS26	N/A	N/A

*Lowest Ranking Corresponds to Highest RDII.



N
W E
S
0 1,500 3,000
Feet
1 inch = 3,000 feet

Jones Falls
Herring Run
High Level
Outfall
Gwynns Falls
Low Level
Dundalk
Patapsco

LEGEND

- DEAD RUN
- FOREST PARK
- GWYNNS FALLS
- MAIDENS CHOICE
- WALBROOK
- POWDER MILL

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City of Baltimore
Department of Public Works

Project No. 1032
Gwynns Falls Sanitary Sewer Evaluation Study
August 2008

Figure 4-1

Interceptor Branch Flow Basins

URS GMB
GEORGE, MILES & BUHR, LLC
ARCHITECTS & ENGINEERS

Table 4-4
Branch Drainage Area Flow Components

	Dry Weather Data		Net Average Daily Flow Rate Diurnal Patterns			Rainfall-Dependent Infiltration & Inflow (RDII) Response to 2-Yr 24-Hr Rainfall Event	
Flow Branch	**Gross Average Waste Water**	**Gross Average Base Infiltration**	**Gross Average Daily Maximum Flow Rate**	**Gross Average Daily Minimum Flow Rate**	**Gross Average Daily Flow Rate**	**Gross RDII Volume**	**Gross Total Design Flow Rate**
Units	**(mgd)**	**(mgd)**	**(mgd)**	**(mgd)**	**(mgd)**	**(million gallons)**	**(mgd)**
Powder Mill							
GF29	2.391	1.697	4.806	3.065	4.088	12.230	16.318
BGF1	0.634	0.659	1.563	0.959	1.294	3.277	4.571
Powder Mill	1.756	1.038	3.243	2.106	2.794	8.953	11.747
Forest Park							
GF24	0.366	0.800	1.328	0.991	1.166	4.898	6.063
Forest Park	0.366	0.800	1.328	0.991	1.166	4.898	6.063
Dead Run							
GFDR1 & GFDR2	4.495	3.164	8.936	5.716	7.659	9.650	17.308
BGF3	0.687	0.376	1.336	0.616	1.063	2.387	3.450
BGF4	2.109	1.779	4.523	3.036	3.888	6.200	10.089
Dead Run	1.699	1.009	3.076	2.063	2.707	1.062	3.769
Walbrook							
GF14	0.125	0.267	0.471	0.312	0.392	1.342	1.734
Walbrook	0.125	0.267	0.471	0.312	0.392	1.342	1.734
Gwynns Falls							
TSGF03 & TSGF04	18.673	18.438	42.598	27.574	37.111	50.446	87.558
Powder Mill	1.756	1.038	3.243	2.106	2.794	8.953	11.747
Forest Park	0.366	0.800	1.328	0.991	1.166	4.898	6.063
Walbrook	0.125	0.267	0.471	0.312	0.392	1.342	1.734
Dead Run	1.699	1.009	3.076	2.063	2.707	1.062	3.769
BGF2	10.040	2.850	17.313	6.978	12.891	52.465	65.356
Gwynns Falls	4.688	12.473	17.166	15.125	17.161	-18.273	-1.111
Maiden's Choice							
GF01A	0.002	0.007	0.011	0.007	0.009	0.120	0.129
GF01B	0.335	0.221	0.734	0.321	0.556	0.747	1.303
GF02	2.337	1.604	4.982	2.913	3.941	8.455	12.396
BGF5	0.416	0.380	1.017	0.540	0.796	1.926	2.722
Maiden's Choice	2.258	1.452	4.710	2.701	3.710	7.395	11.106
Sewershed Total:	**10.891**	**17.040**	**29.995**	**23.297**	**27.931**	**5.377**	**33.308**

Flows Subtracted from Upstream Branch Interceptor

Represents Site Specific Values that appear to be Invalid/Irregular

Note: Total includes flows from all drainage basins within the City portion of the sewershed and excludes flows from Baltimore County.

Table 4-5

Branch Flow Comparisons Summary Table

	Waste Water (Sewage Only)				Base Infiltration				RDII Response to 2-yr 24-hr Rain Event				RDII and Base Infiltration		
Interceptor Branch	Branch Waste Water Per Linear Foot of Pipe	Branch Waste Water per Inch-Dia-Mile	Branch Waste Water per Acre	Branch Waste Water % of Gross Dry Weather Average Daily Flow Rate	Branch Base Infiltration Per Linear Foot	Branch Base Infiltration Per Inch-Dia-Mile	Branch Base Infiltration Per Acre	Branch Base Infiltration % of Gross Dry Weather Average Daily Flow Rate	Branch RDII Response Per Linear Foot	Branch RDII Response Per Inch-Dia-Mile	Branch RDII Response Per Acre	"Capture Coefficient" % of Rainfall Entering as RDII	Branch I&I Per Linear Foot of Pipe	Branch I&I Per Inch-Dia-Mile	Branch I&I Per Acre
Units	(gpd/LF)	(gpd/in-dia-mi)	(gpd/acre)	(%)	(gpd/LF)	(gpd/in-dia-mi)	(gpd/acre)	(%)	(gpd/LF)	(gpd/in-dia-mi)	(gpd/acre)	(%)	(gpd/LF)	(gpd/in-dia-mi)	(gpd/acre)
Powder Mill	5.53	3,045	1,083	62.85%	3.27	1,800	640	37.15%	28.18	15,523	5,519	8.62%	31.44	17,322	6,159
Forest Park	2.54	1,409	429	31.36%	5.55	3,082	939	68.63%	33.98	18,867	5,750	6.57%	39.53	21,950	6,689
Walbrook	1.66	970	392	31.78%	3.56	2,083	842	68.22%	17.85	10,453	4,228	8.41%	21.40	12,536	5,070
Dead Run	13.26	6,938	1,459	62.74%	7.87	4,121	867	37.27%	8.29	4,337	912	9.47%	16.16	8,458	1,778
Gwynns Falls	14.46	4,370	2,369	27.32%	38.47	11,629	6,304	72.68%	-56.35	-17,035	-9,234	13.67%	-17.88	-5,407	-2,931
Maiden's Choice	8.36	4,870	1,229	60.86%	5.38	3,132	790	39.14%	27.39	15,951	4,024	5.80%	32.77	19,084	4,815
Branch Average	7.63	3,600	1,160	46.15%	10.68	4,308	1,730	53.85%	9.89	8,016	1,866	8.76%	20.57	12,324	3,597

Represents Site Specific Values that appear to be Invalid/Irregular

The highest peak instantaneous flow rate recorded from the sewershed as a whole occurred in response to the 2.34 inch rainfall event on November 16, 2006 which lasted 10 hours. This rainfall event corresponds roughly to a 1-year 12-hour rainfall event (2.30 inches over 12 hours). The November 16, 2006 rain event produced peak instantaneous flow rates of 29.140 mgd at TSGF03, 128.174 mgd at TSGF04, and 11.266 mgd at GF02 for a total of 168.580 mgd. (Due to the effects of time of concentration and flow attenuation, peak instantaneous flow rates do not occur at the same time and therefore are not typically summed. However, for a rough comparison between flows projected in response to the theoretical 2-year 24-hour rainfall event calculated as part of this report and actual flows recorded in the sewershed, this type of addition can be useful.) To determine the volumetric response to the November 16, 2006 rainfall event, the total volume from each flow meter was calculated for the 24-hour period corresponding to the start of the rainfall event. The total volumes are 20.820 million gallons at TSGF03, 46.143 million gallons at TSGF04, and 7.780 million gallons at GF02 for a total of 74.743 million gallons.

To isolate the portion of flow from the City area alone, the peak instantaneous flow rates and 24-hour flow total from the five border flow meters for the November 16, 2006 rain event are as follows:

A. Peak Instantaneous Flow Rates
2.456 mgd at BGF1, 63.921 mgd at BGF2, 5.210 mgd at BGF3, 13.118 mgd at BGF4, and 2.452 mgd at BGF5 for a total of 87.157 mgd.

B. Total 24-hour Flow Total
1.921 million gallons at BGF1, 26.951 million gallons at BGF2, 2.463 million gallons at BGF3, 6.776 million gallons at BGF4, and 1.583 million gallons at BGF5 for a total of 39.694 million gallons.

Subtracting out flows from Baltimore County, the City portion of the sewershed totals are 168.580 – 87.157 = 81.423 mgd peak instantaneous flow rate and 74.743 – 39.694 = 35.049 million gallons volumetric total in response to the November 16, 2006 rain event.

Comparing the individual flow meter basin flow totals presented in Table 4-1 to actual flows recorded at these three flow meters produces results that are not reasonable. Table 4-1 indicates that a total flow rate of 96.851 mgd can be anticipated in response to a 2-year 24-hour rainfall event across the portion of Gwynns Falls sewershed located in the City. This total does not include the Baltimore County flows and represents the total flow for the 24-hour period. The peak instantaneous flow rate would be even higher at the peak of the rain event when applied to the design rain event curve. Compared to the November 16, 2006 rain event flow total of 35.049 mgd, the response to the 2-year 24-hour rainfall event appears to be too high. Considering that the actual November 16, 2006 event is a 1-year 12-hour rainfall being compared to a theoretical 2-year 24-hour rainfall event there should be some difference in flow totals. However, the difference between the 24-hour volume should not be as large as this comparison shows.

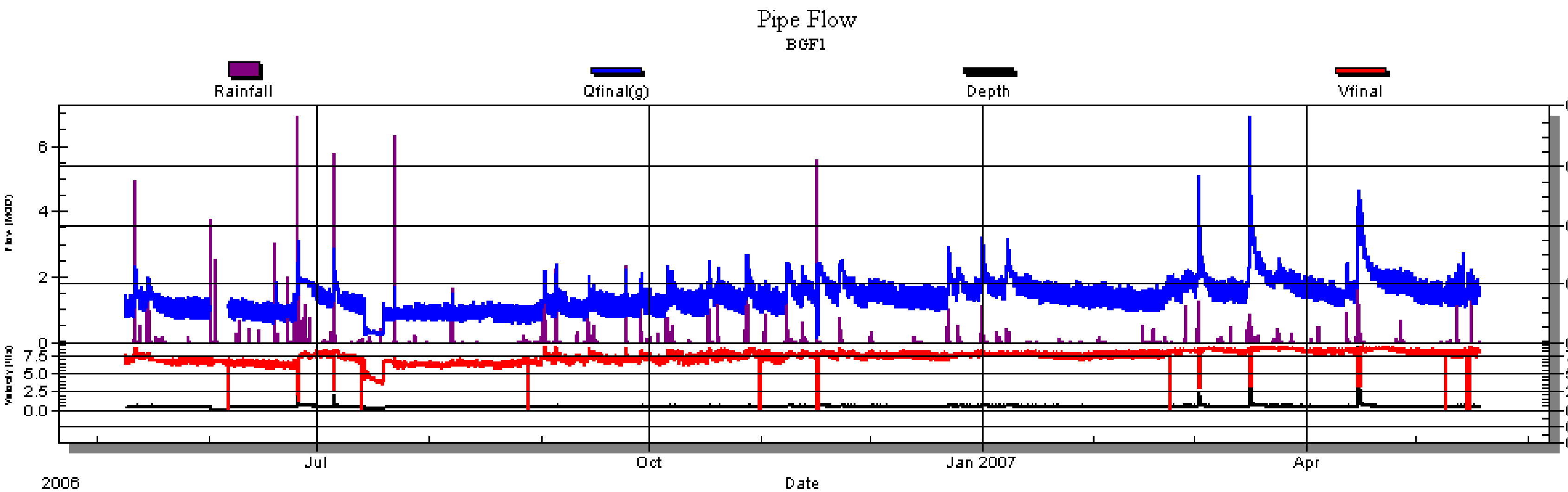
There are several factors that could impact the Sliicer analysis or contribute to inconsistencies between the sum of the individual flow meter site totals compared to the flows recorded at the downstream end of the sewershed:

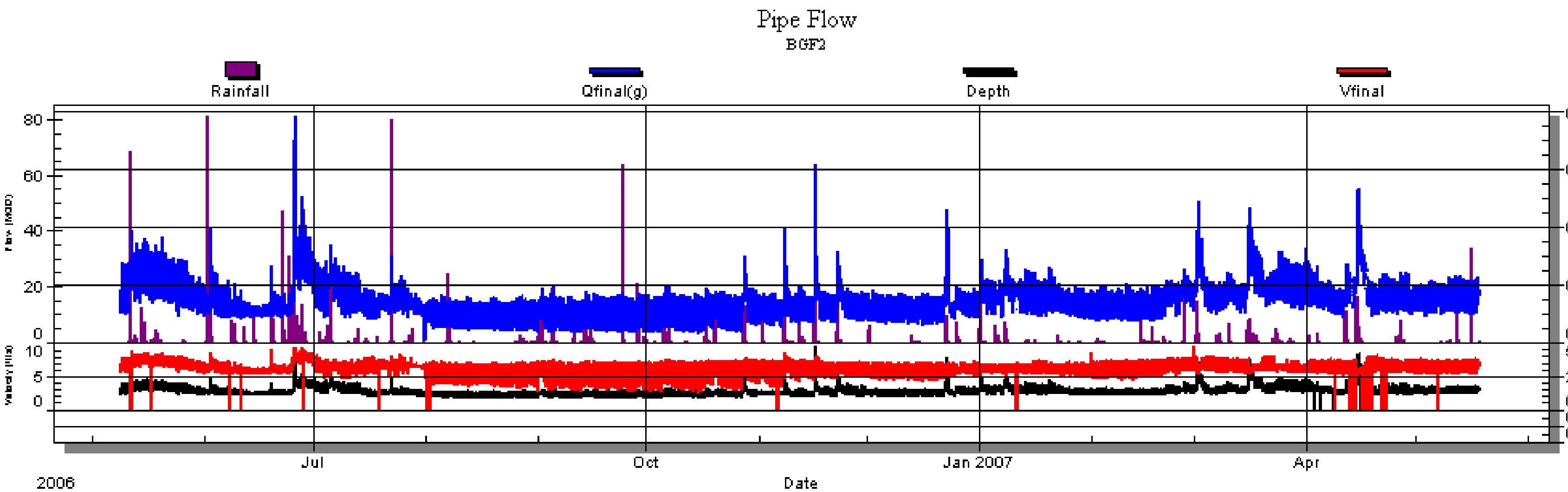
A. Spatial Distribution of Rainfall – The process of calculating the RDII response to a single theoretical rainfall event, equivalent to a 2-year 24-hour magnitude occurring uniformly over the sewershed, may be too hypothetical to compare the sum to actual flows.

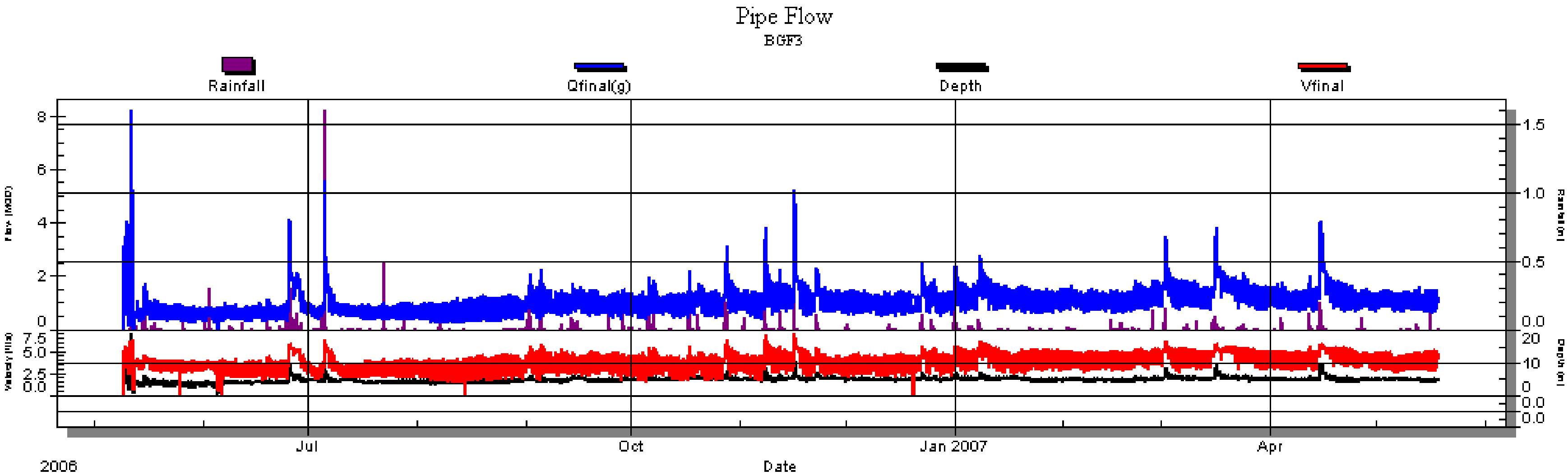
B. Steady State Vs. Dynamic Analysis – Peak instantaneous flow rates are not cumulative due to the effect of time of concentration. Flows entering the system at the upstream reaches may take several hours to reach the bottom of the system whereas flows entering near the bottom may take only a few minutes. Therefore peak flow rates affect the bottom of the system over a longer period of time as the flow is attenuated.

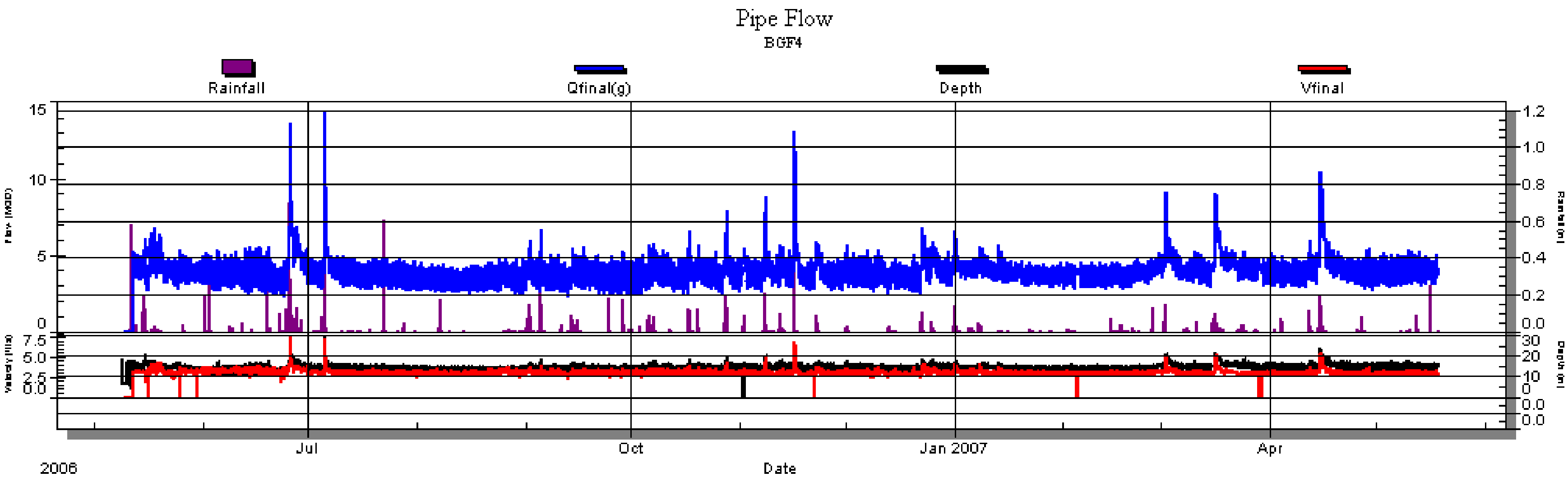
C. Limits of Pipe Capacity and Possible Overflows – The actual flow rates recorded near the downstream end of the sewershed may have been constricted by the capacity of the pipes where the flow meters were located whereas the sum of the flow totals is not so affected. Also, any flows exiting the system are not accounted for in this comparison.

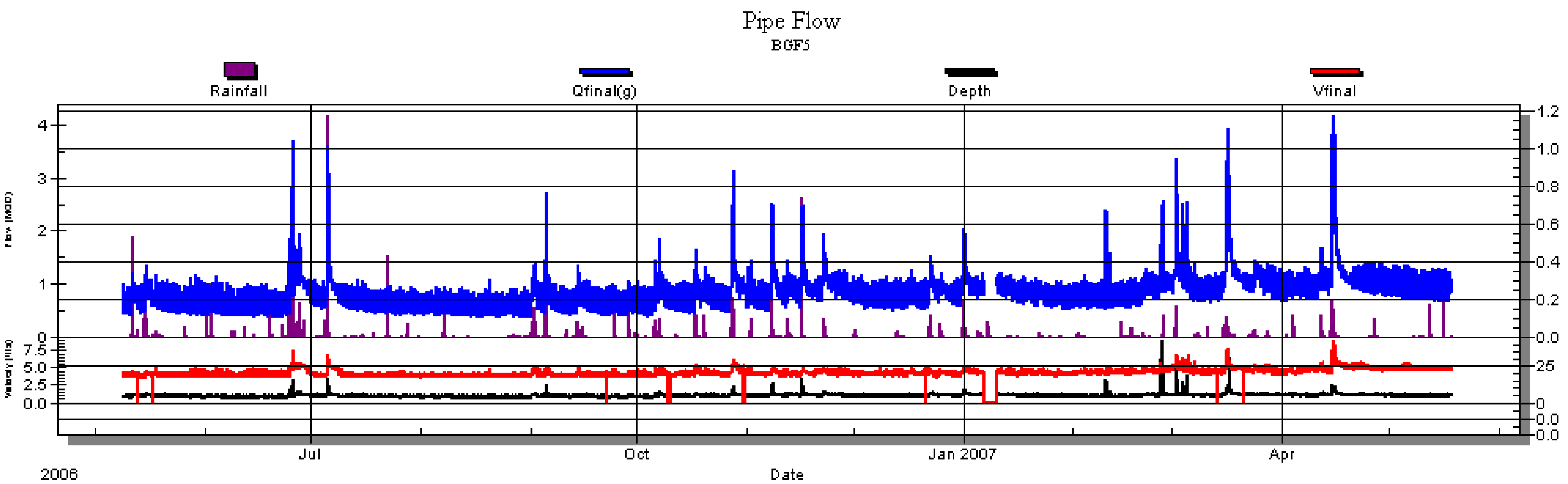
Based on this comparison and the factors noted above, it is recommended that the hydraulic modeling tasks consider these issues during the calibration process to verify that the theoretical flows projected at the bottom of sewershed reasonably compare to actual flow conditions experienced, within the tolerances of the modeling process.

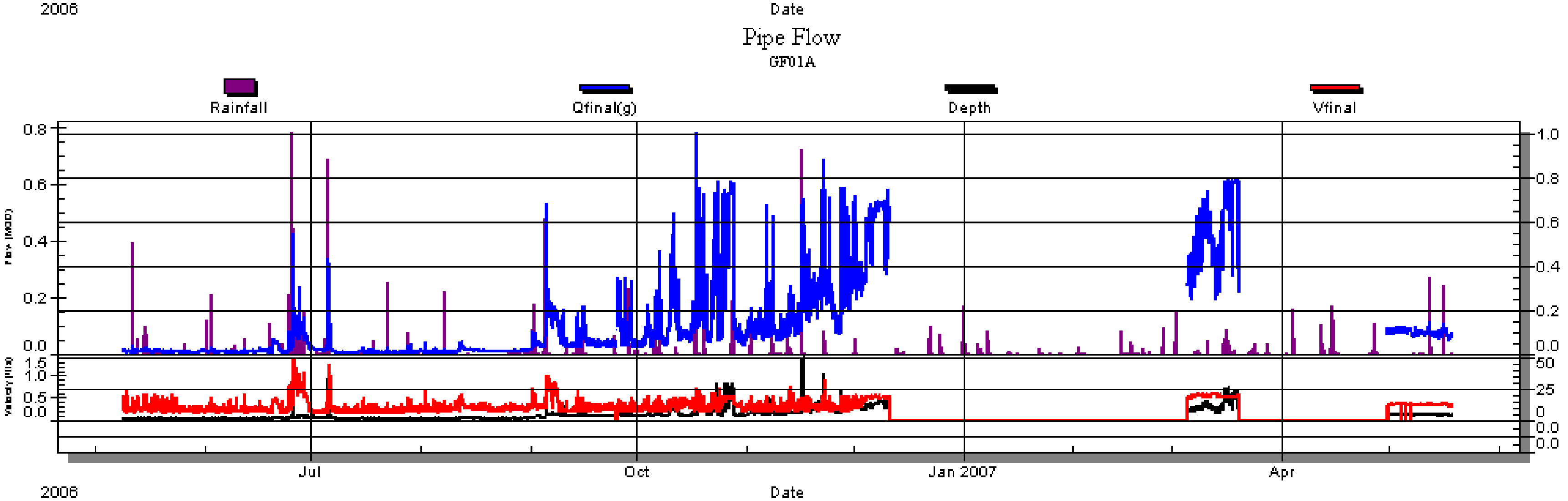

Pipe Flow
BGF1
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date

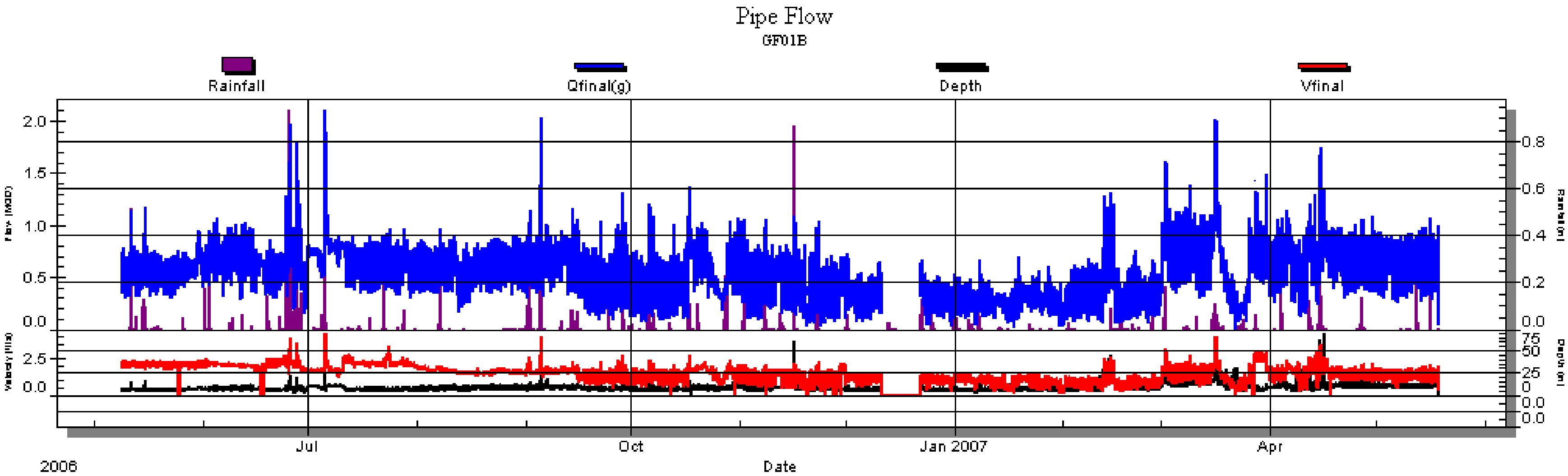

Pipe Flow
BGF2
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date

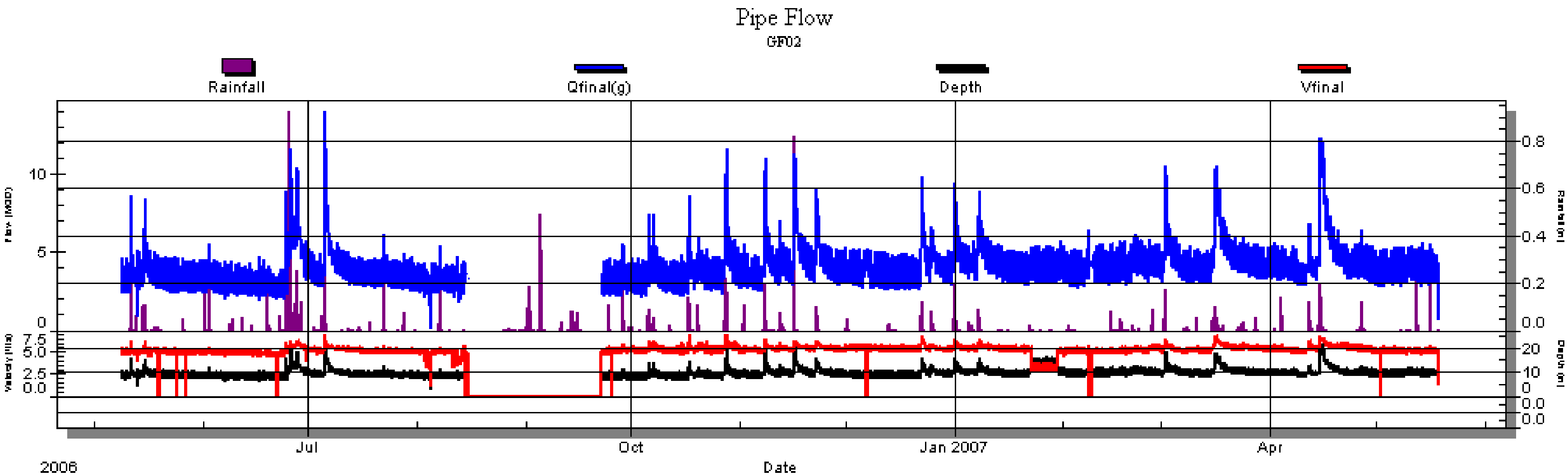

Pipe Flow
BGF3
Rainfall
Qfinal(g)
Depth
Vfinal
8
6
4
2
0
7.5
5.0
2.5
0.0
1.5
1.0
0.5
0.0
20
10
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date

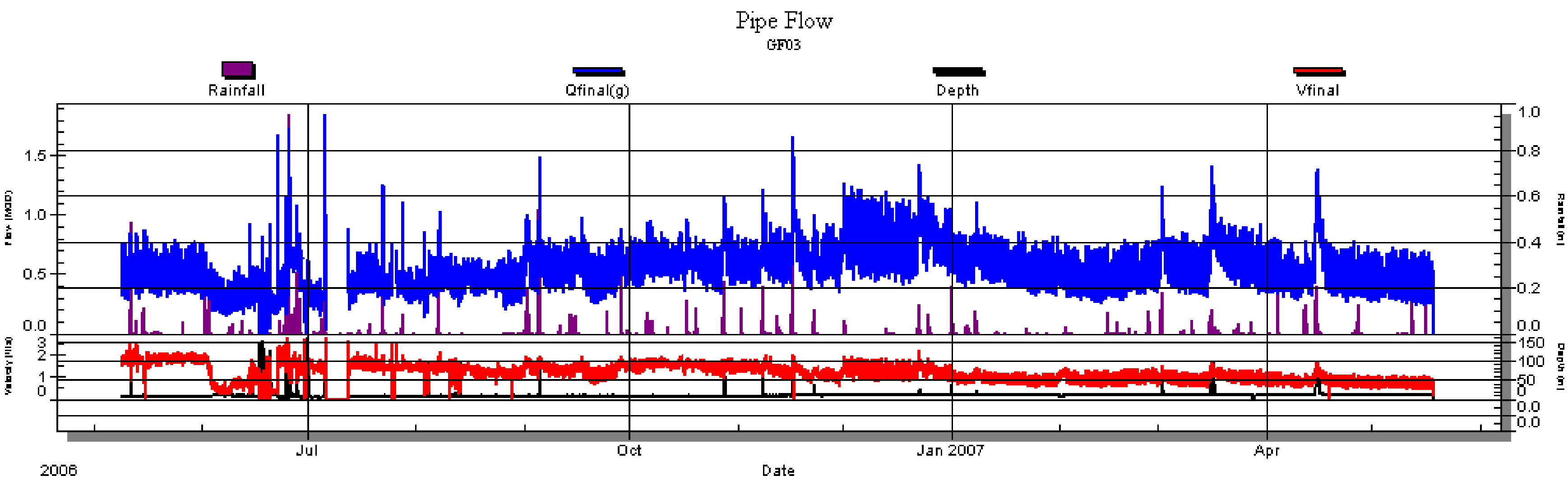

Pipe Flow
BGF4
Rainfall
Qfinal(g)
Depth
Vfinal
15
10
5
0
7.5
5.0
2.5
0.0
1.2
1.0
0.8
0.6
0.4
0.2
0.0
30
20
10
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date

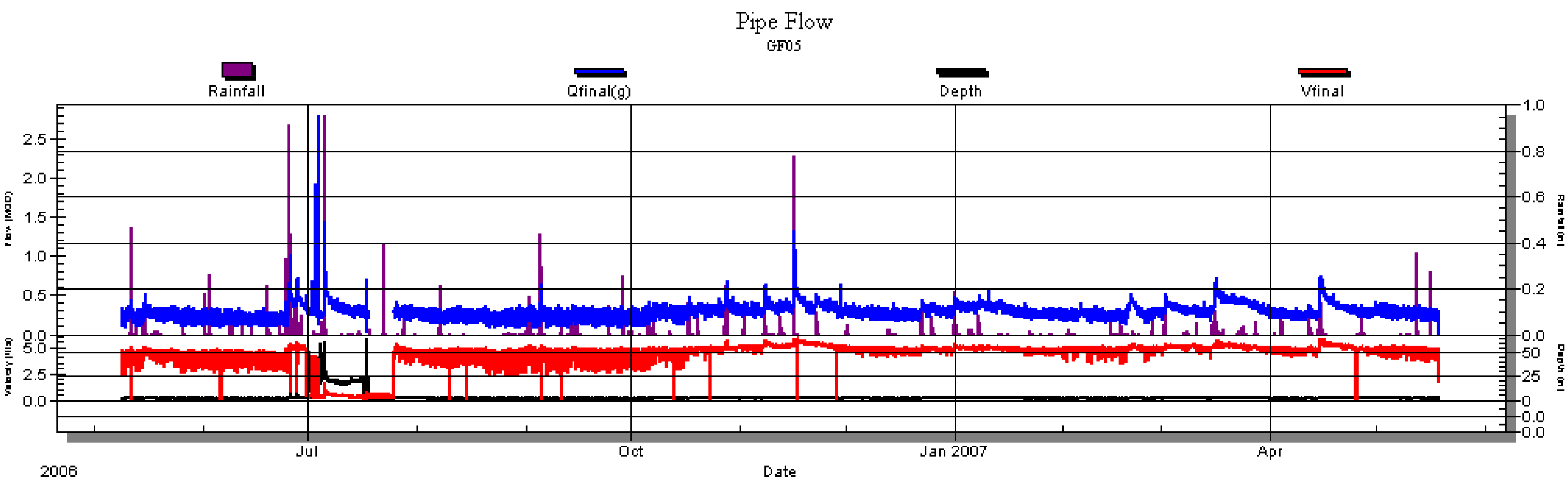

Pipe Flow
BGF5
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date

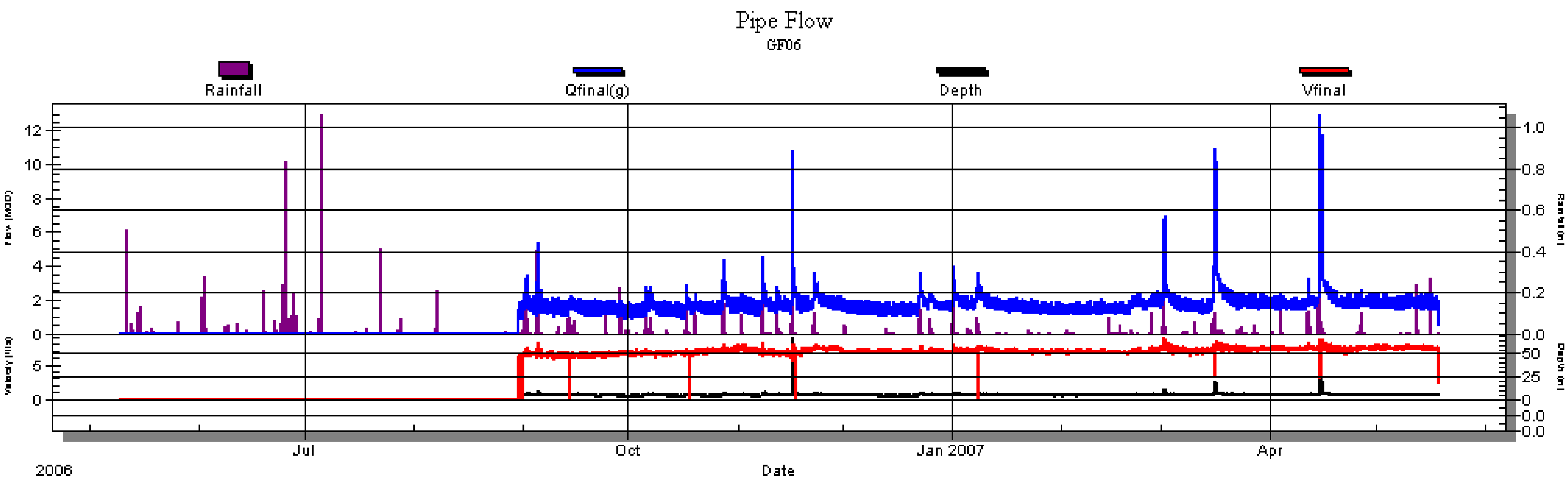

Pipe Flow
GF01A
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date


Pipe Flow
GF01B
Rainfall
Qfinal(g)
Depth
Vfinal
Date
Jul
Oct
Jan 2007
Apr
2006


Pipe Flow
GF02
Rainfall
Qfinal(g)
Depth
Vfinal
Date
Jul
Oct
Jan 2007
Apr
2006


Pipe Flow
GF03
Rainfall
Qfinal(g)
Depth
Vfinal
1.5
1.0
0.5
0.0
3
2
1
0
1.0
0.8
0.6
0.4
0.2
0.0
150
100
50
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date


Pipe Flow
GF05
Rainfall
Qfinal(g)
Depth
Vfinal
2.5
2.0
1.5
1.0
0.5
0.0
5.0
2.5
0.0
1.0
0.8
0.6
0.4
0.2
0.0
50
25
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date


Pipe Flow
GF06
Rainfall
Qfinal(g)
Depth
Vfinal
12
10
8
6
4
2
0
5
0
1.0
0.8
0.6
0.4
0.2
0.0
50
25
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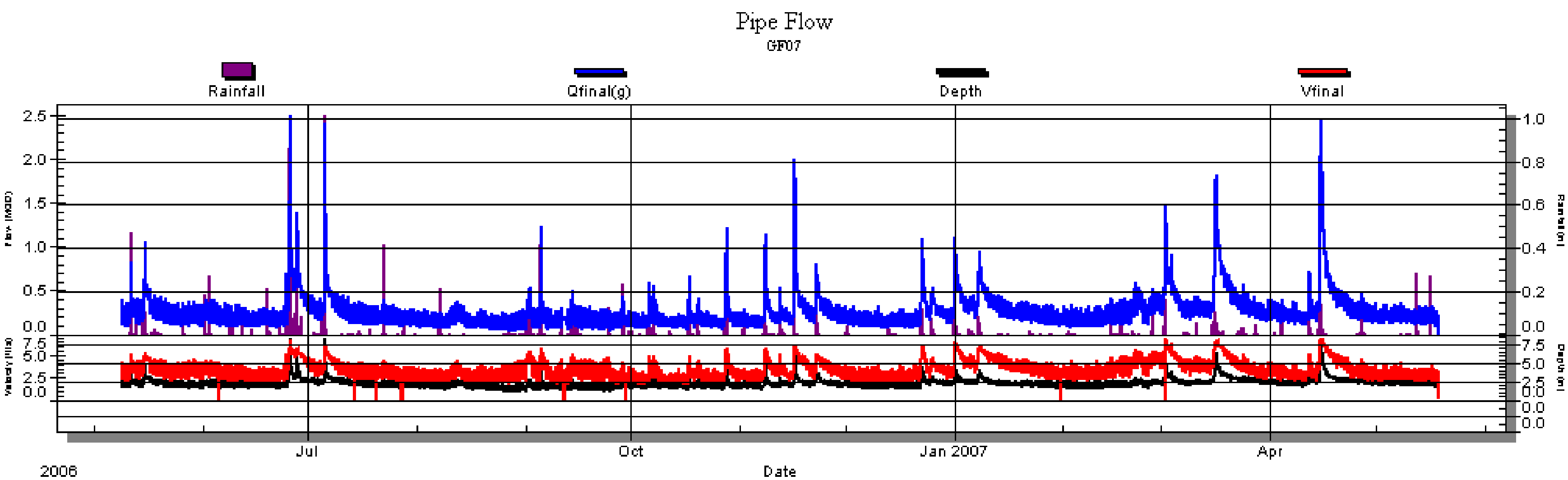
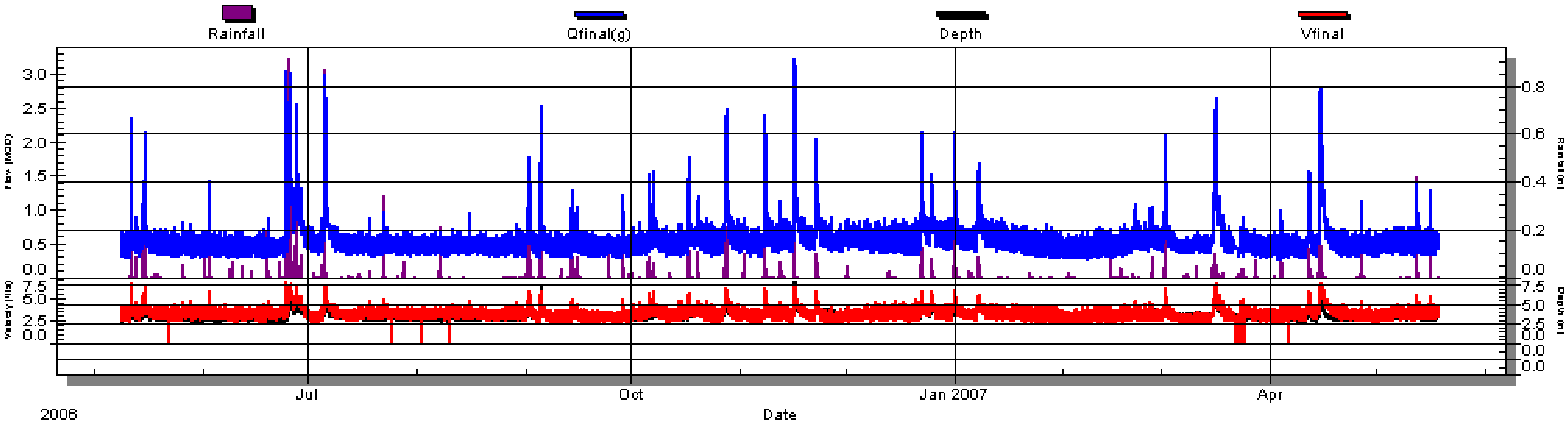
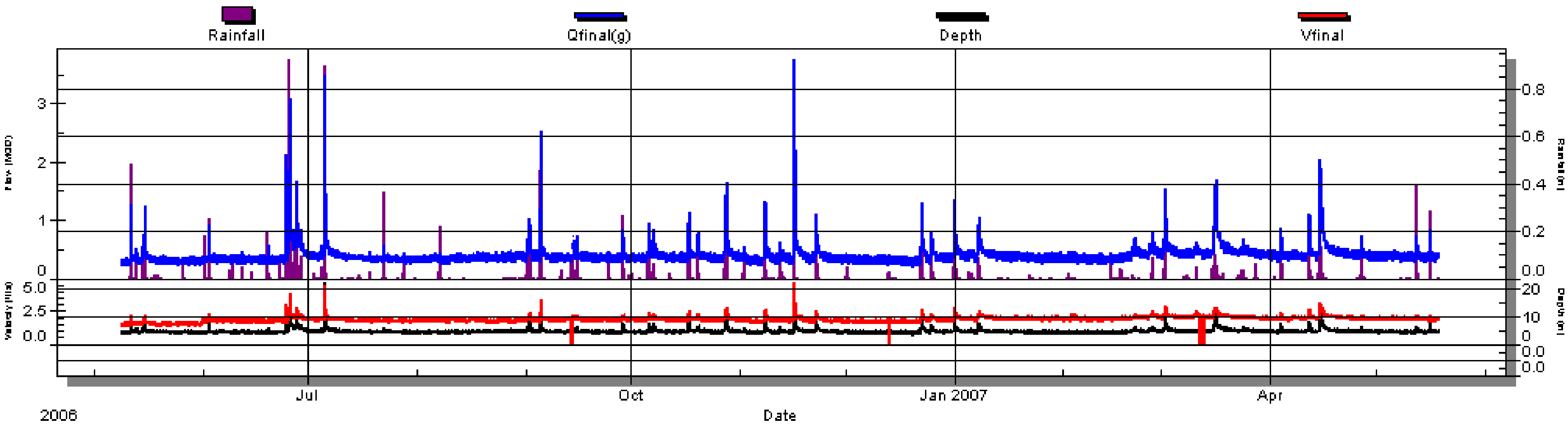
Jul
Oct
Jan 2007
Apr
2006
Date


Pipe Flow
GF07
Rainfall
Qfinal(g)
Depth
Vfinal
2.5
2.0
1.5
1.0
0.5
0.0
7.5
5.0
2.5
0.0
1.0
0.8
0.6
0.4
0.2
0.0
Jul
Oct
Jan 2007
Apr
2006
Date

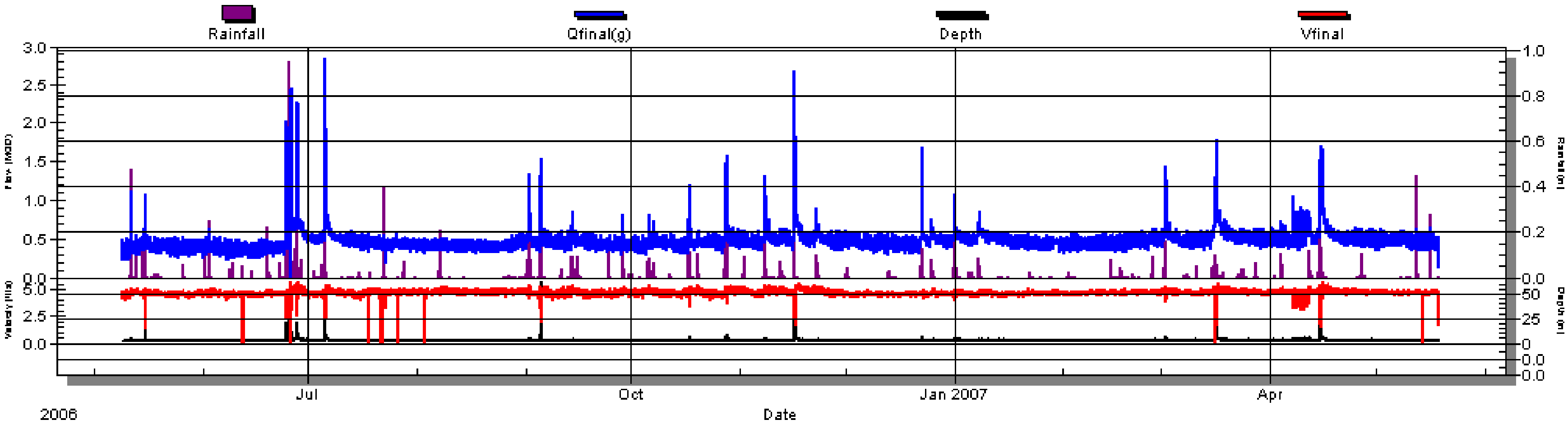
Pipe Flow
GF08



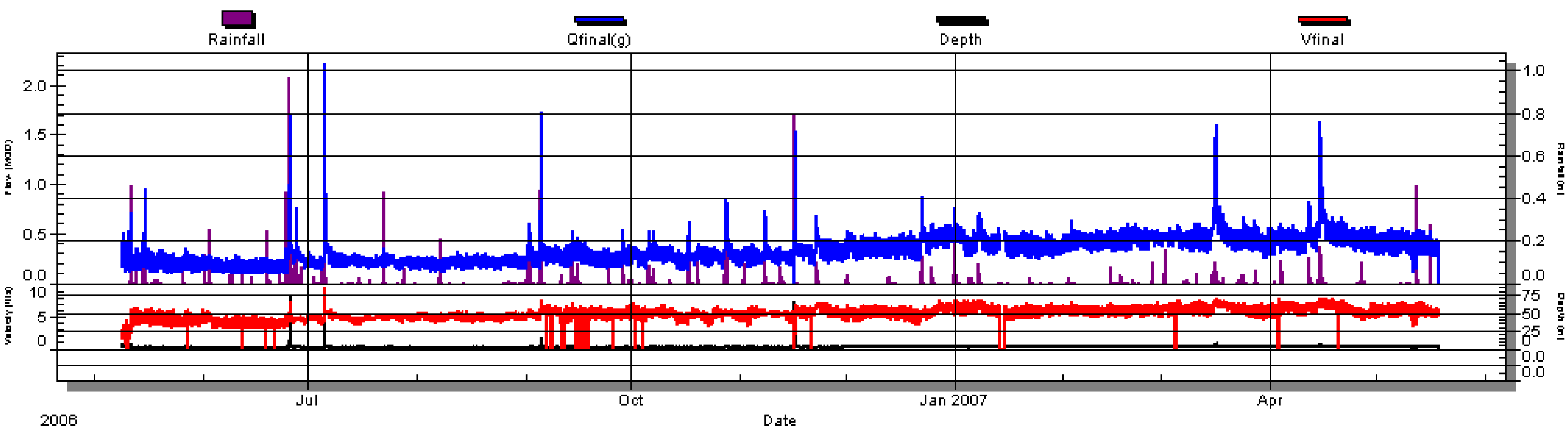
Pipe Flow
GF09

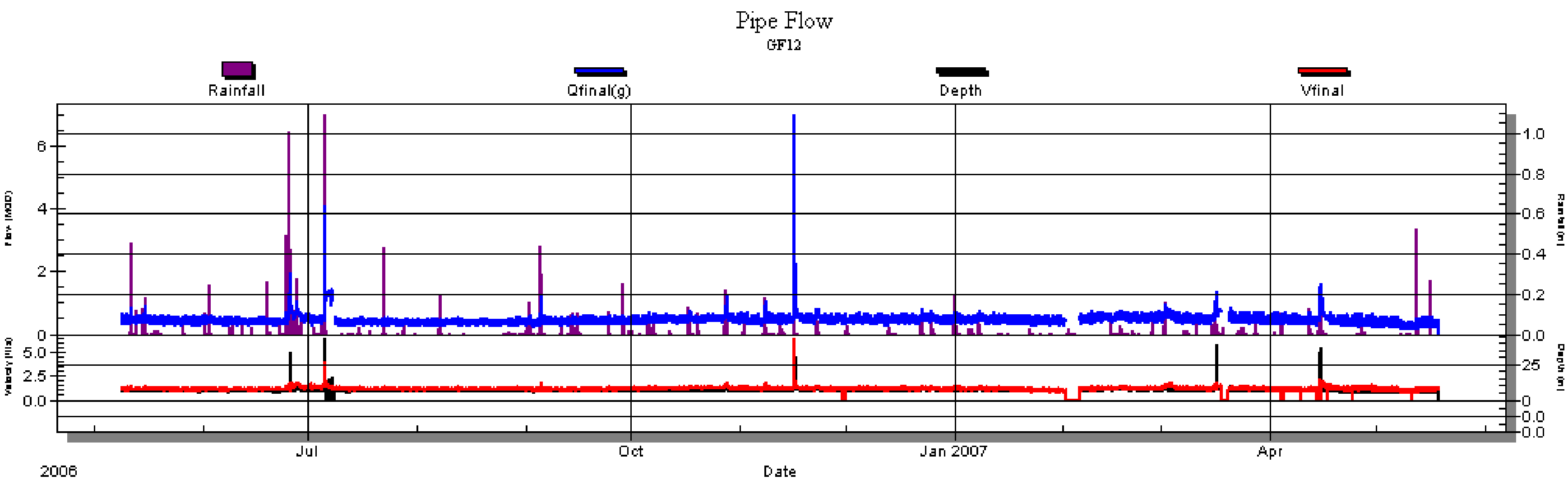


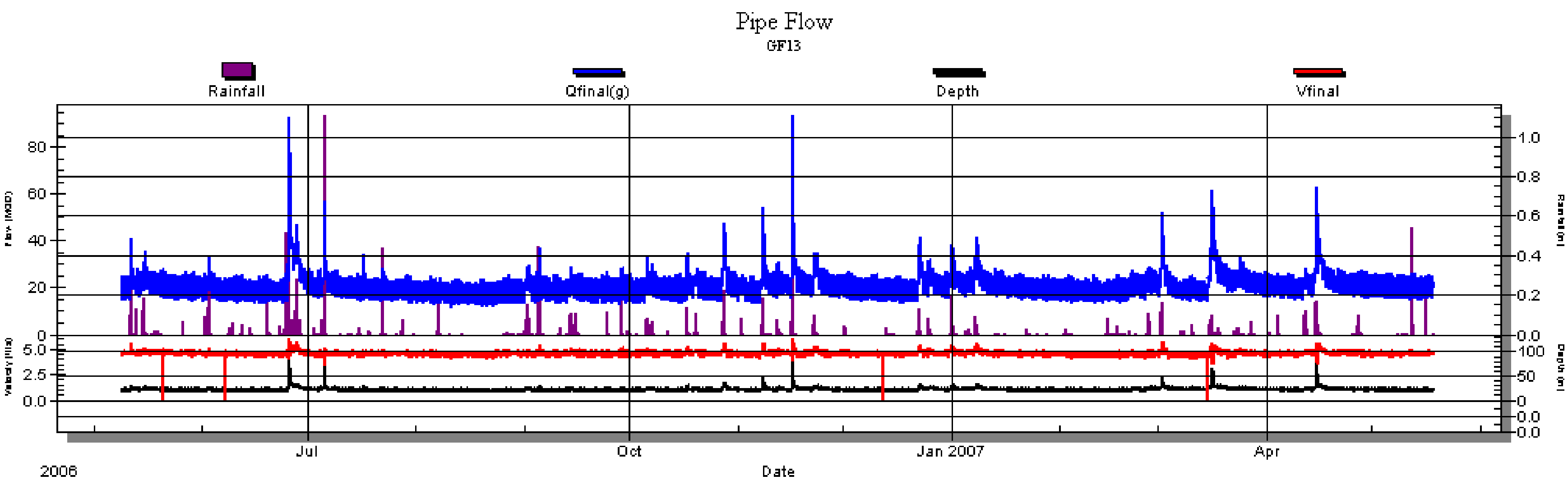
Pipe Flow
GF10

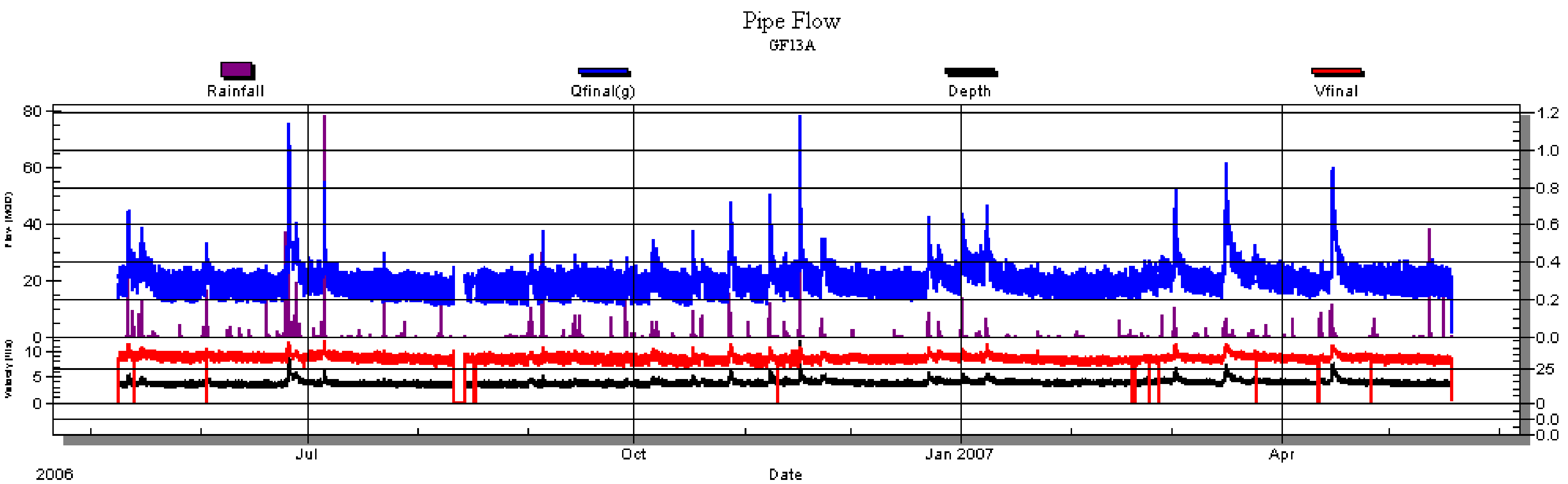


Pipe Flow
GF11




Pipe Flow
GF12
Rainfall
Qfinal(g)
Depth
Vfinal
Date
2006
Jul
Oct
Jan 2007
Apr


Pipe Flow
GF13
Rainfall
Qfinal(g)
Depth
Vfinal
Date
2006
Jul
Oct
Jan 2007
Apr



Pipe Flow
GF13A
Rainfall
Qfinal(g)
Depth
Vfinal
80
60
40
20
0
10
5
0
1.2
1.0
0.8
0.6
0.4
0.2
0.0
25
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
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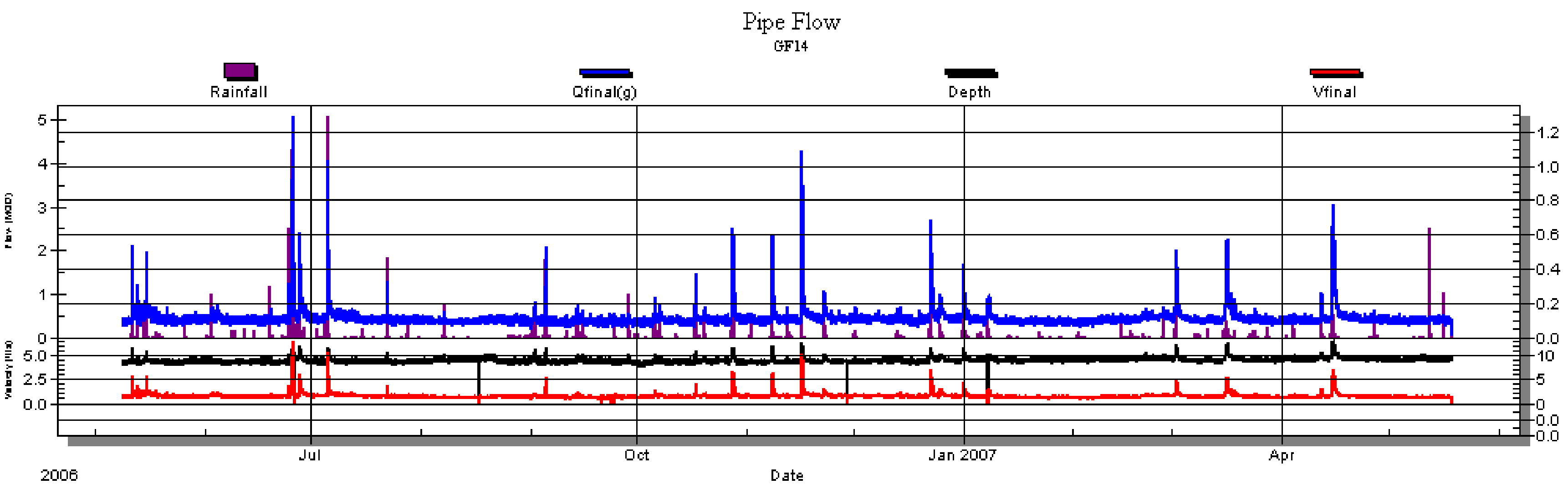
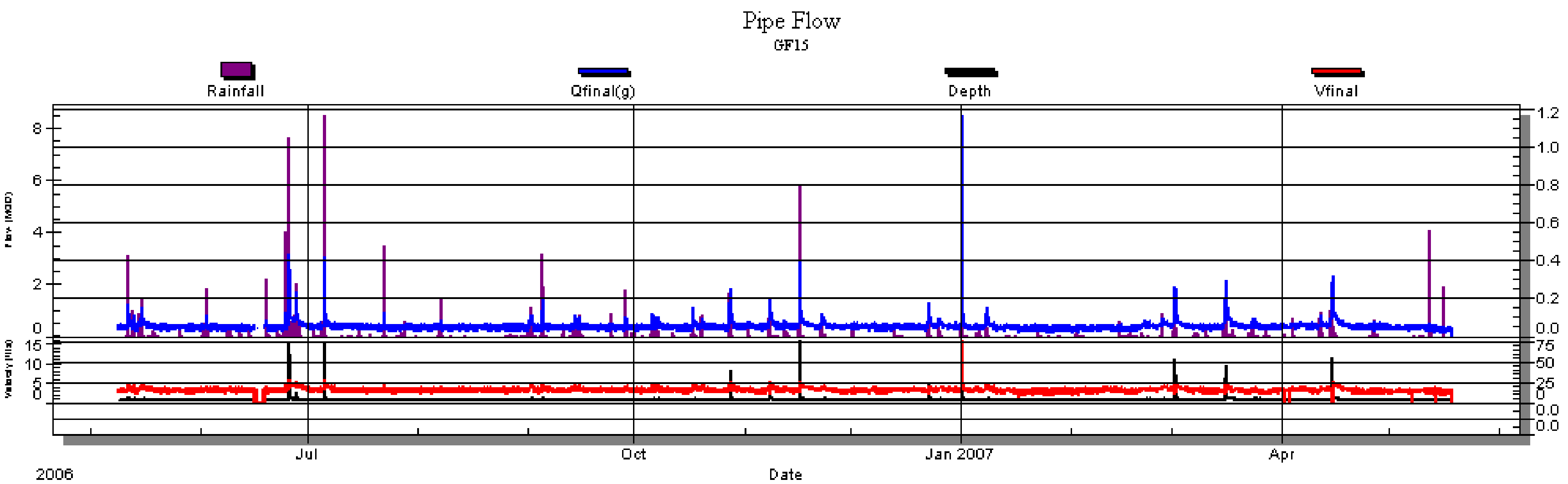
Date



Pipe Flow
GF14
Rainfall
Qfinal(g)
Depth
Vfinal
5
4
3
2
1
0
5.0
2.5
0.0
1.2
1.0
0.8
0.6
0.4
0.2
0.0
10
5
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date


Pipe Flow
GF15
Rainfall
Qfinal(g)
Depth
Vfinal
8
6
4
2
0
15
10
5
0
1.2
1.0
0.8
0.6
0.4
0.2
0.0
75
50
25
0
0.0
0.0
Jul
Oct
Jan 2007
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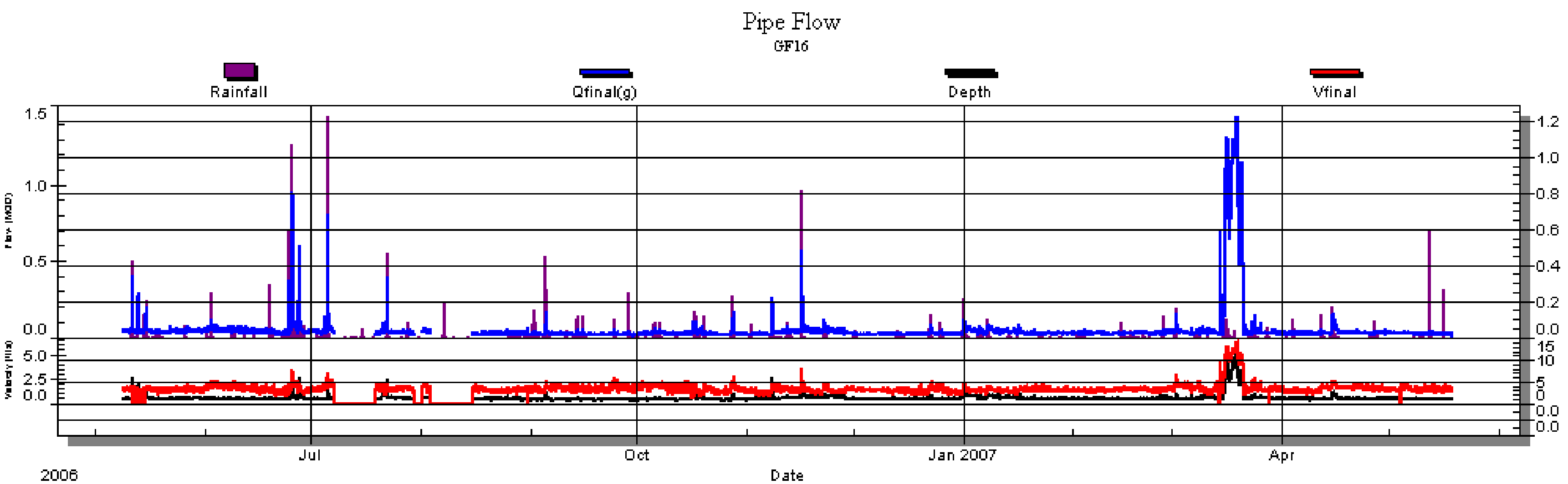
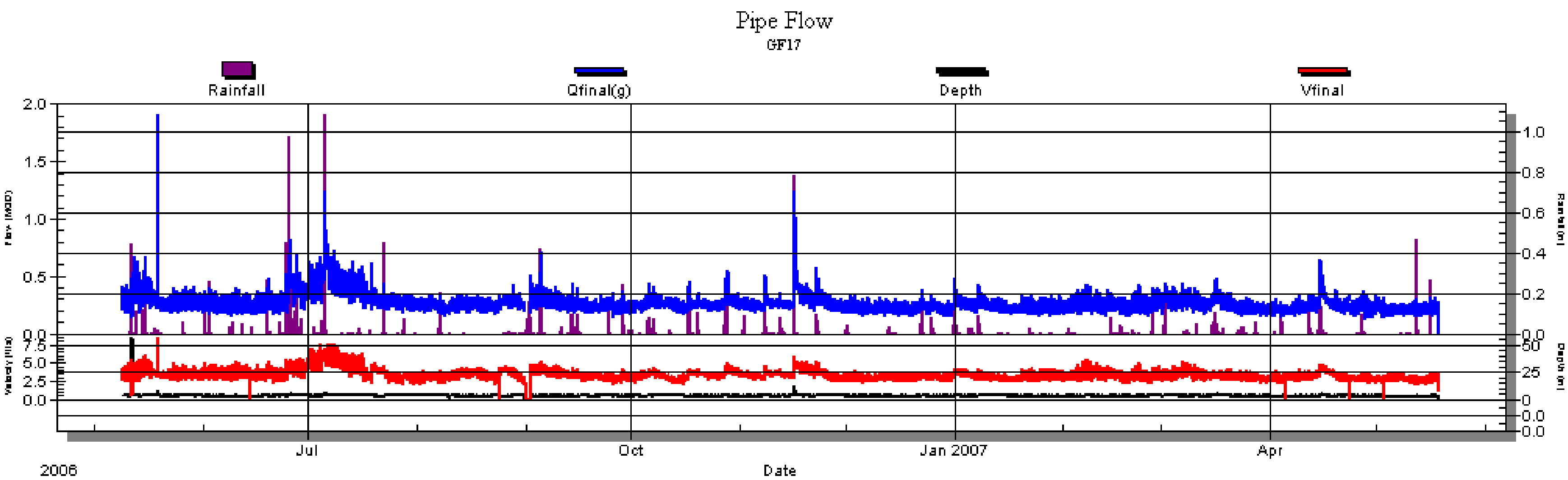
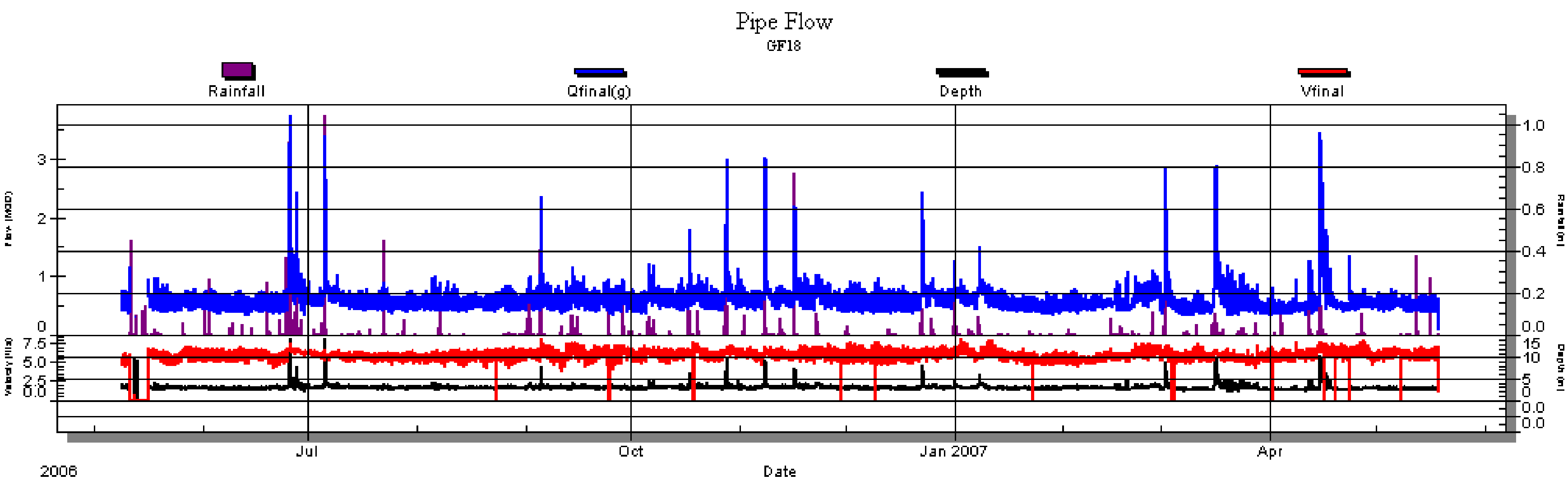
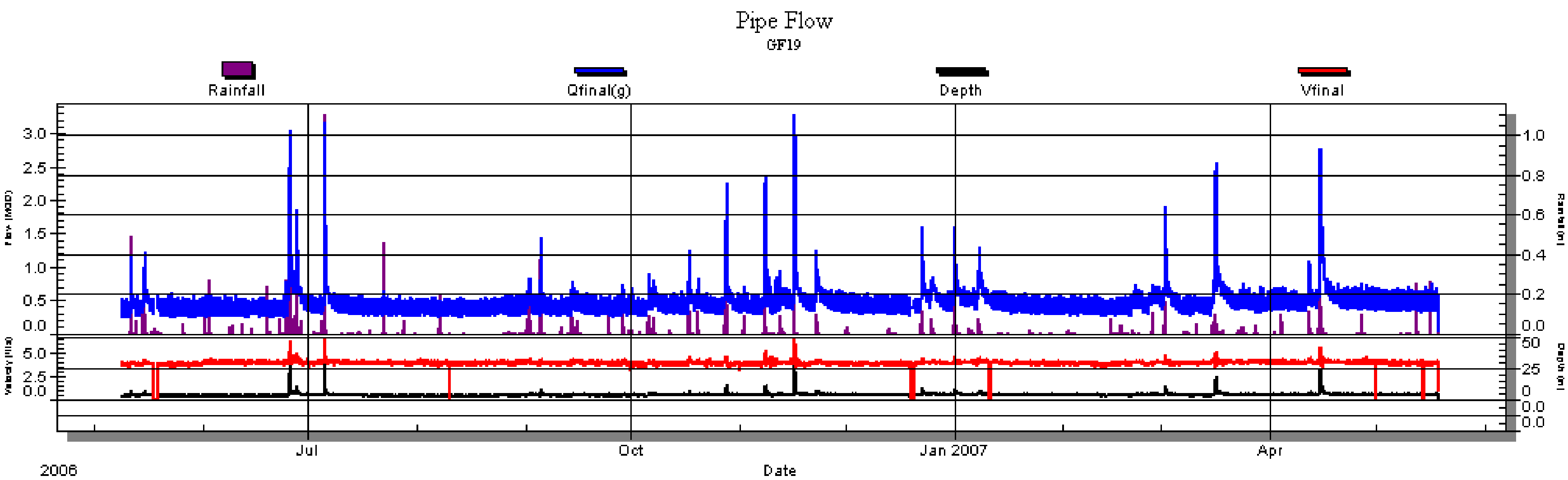
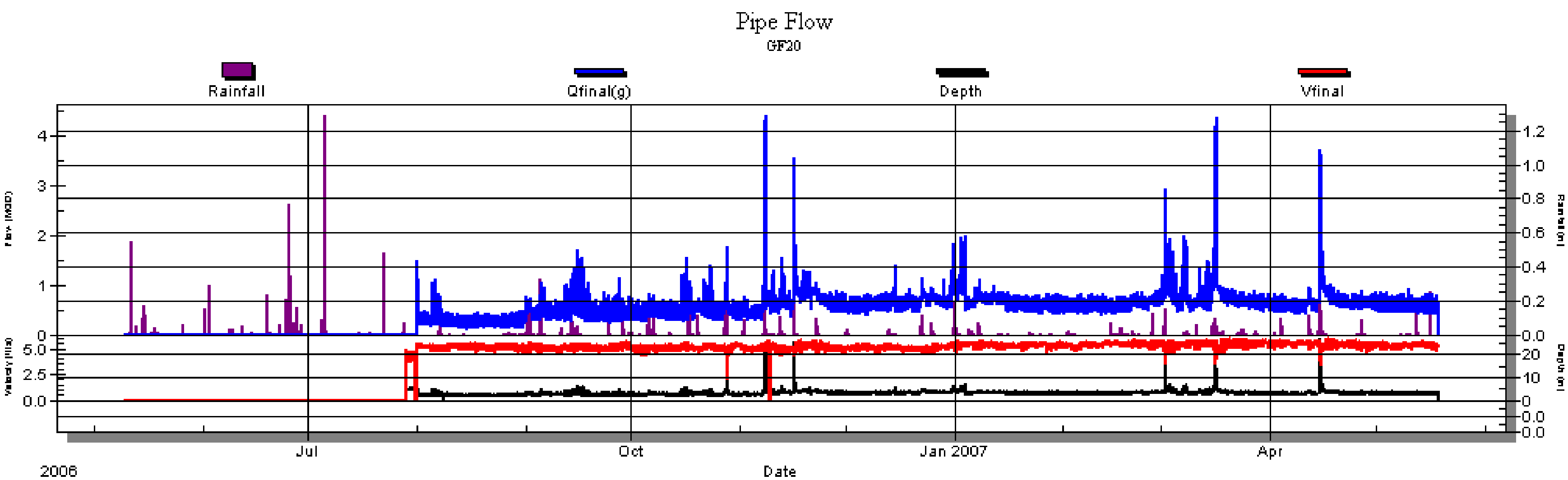
2006
Date


Pipe Flow
GF16
Rainfall
Qfinal(g)
Depth
Vfinal
1.5
1.0
0.5
0.0
5.0
2.5
0.0
1.2
1.0
0.8
0.6
0.4
0.2
0.0
15
10
5
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date


Pipe Flow
GF17
Rainfall
Qfinal(g)
Depth
Vfinal
Date
2006
Jul
Oct
Jan 2007
Apr


Pipe Flow
GF18
Rainfall
Qfinal(g)
Depth
Vfinal
Date
2006
Jul
Oct
Jan 2007
Apr


Pipe Flow
GF19
Rainfall
Qfinal(g)
Depth
Vfinal
3.0
2.5
2.0
1.5
1.0
0.5
0.0
5.0
2.5
0.0
1.0
0.8
0.6
0.4
0.2
0.0
50
25
0
Jul
Oct
Jan 2007
Apr
2006
Date


Pipe Flow
GF20
Rainfall
Qfinal(g)
Depth
Vfinal
4
3
2
1
0
5.0
2.5
0.0
1.2
1.0
0.8
0.6
0.4
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20
10
0
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Oct
Jan 2007
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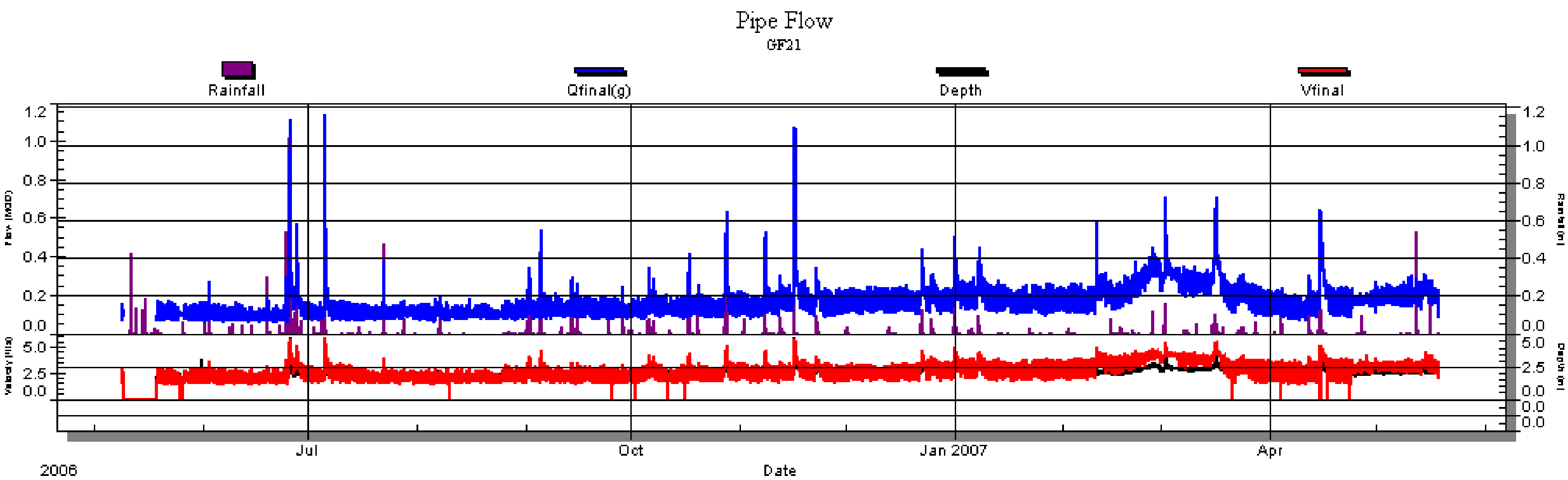
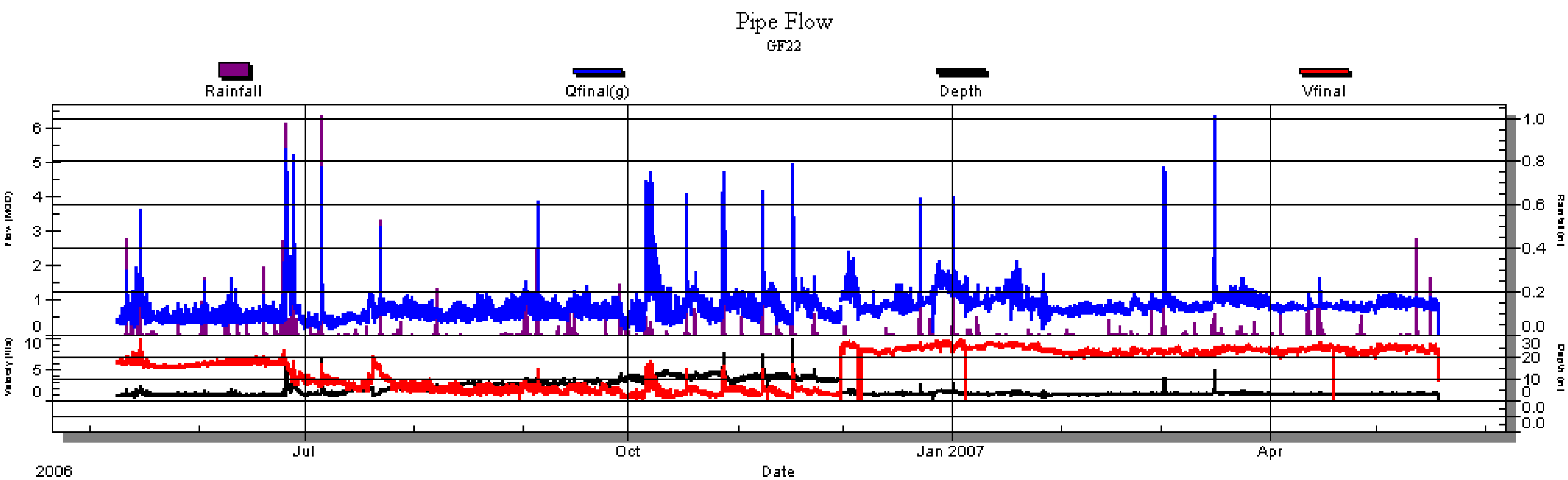
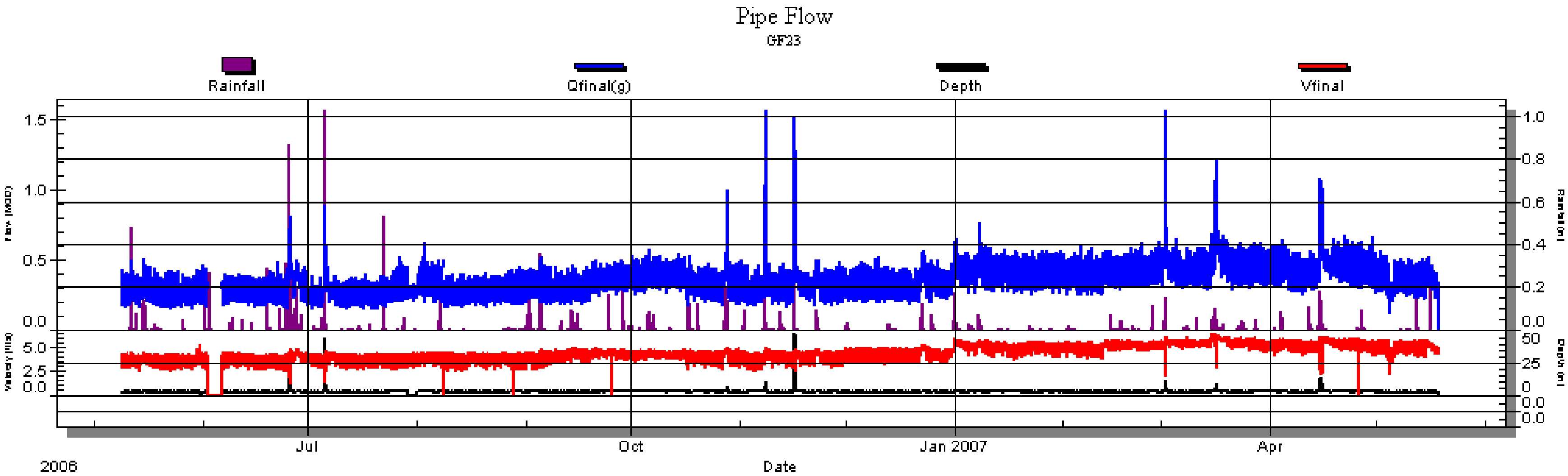
2006
Date


Pipe Flow
GF21
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date


Pipe Flow
GF22
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date


Pipe Flow
GF23
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
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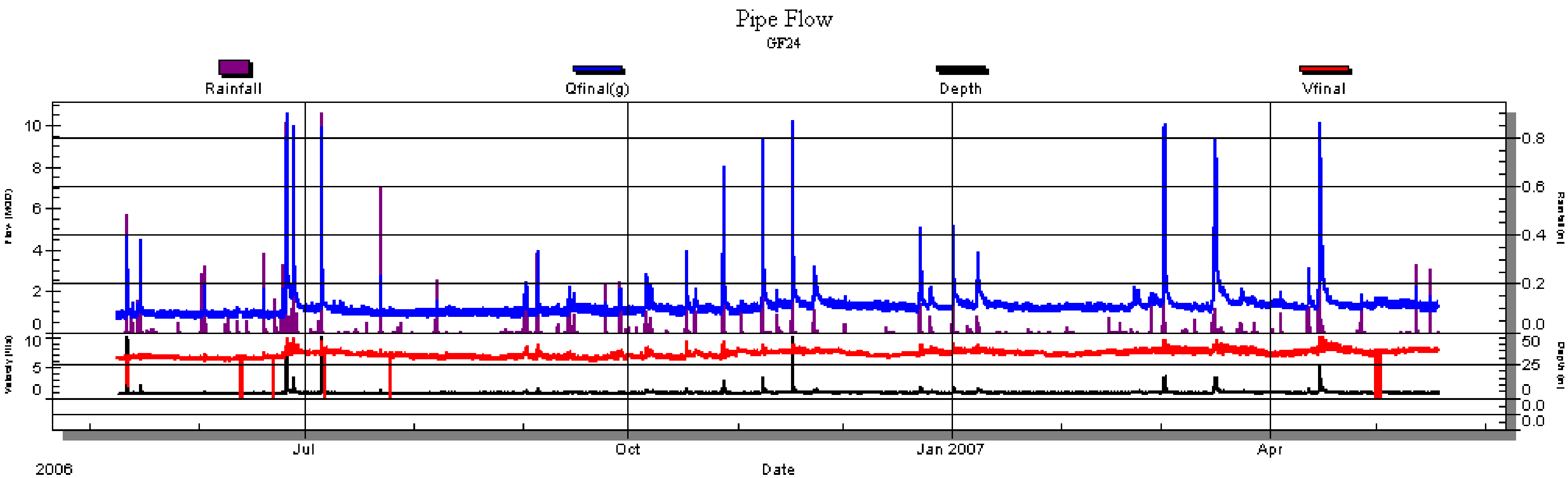
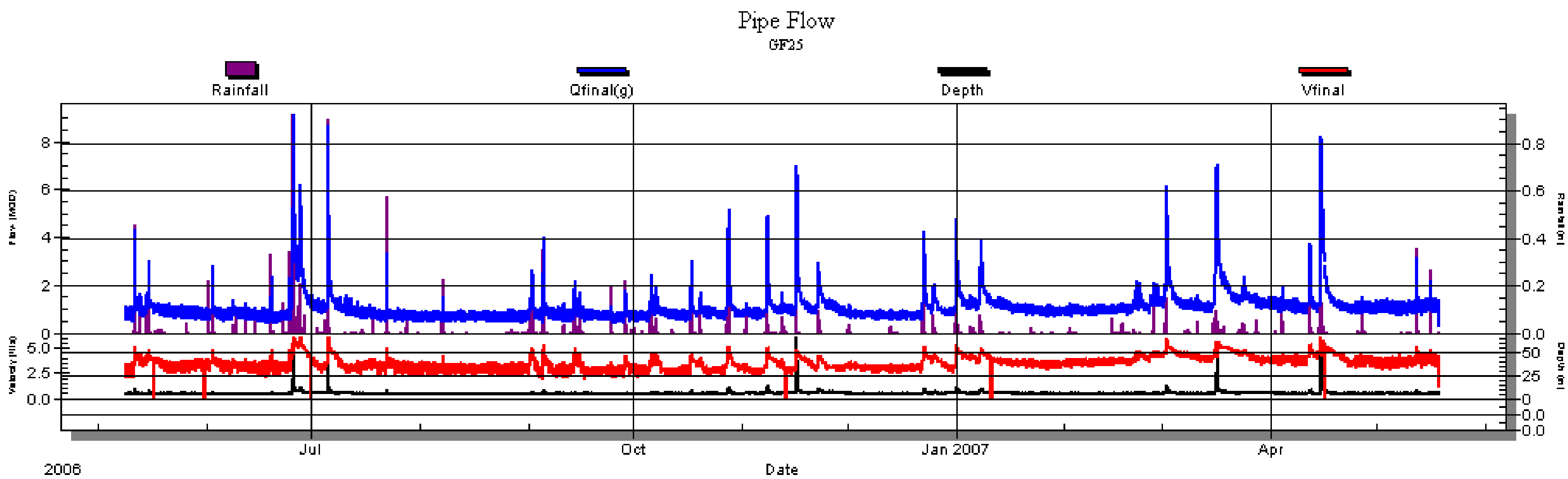
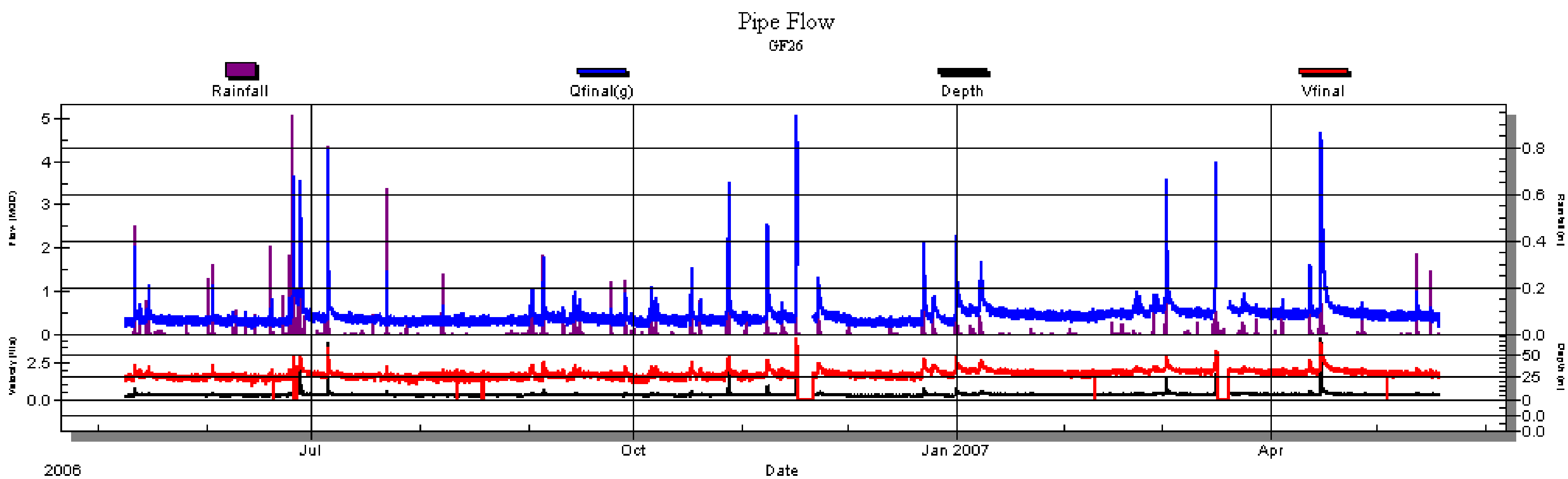
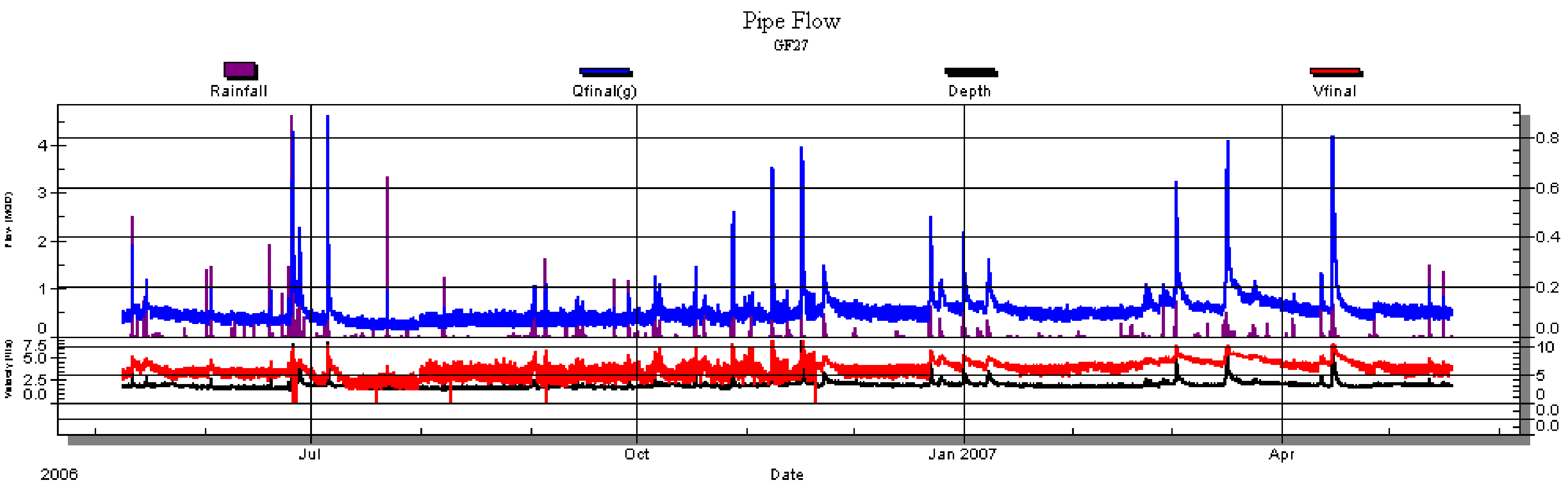
2006
Date

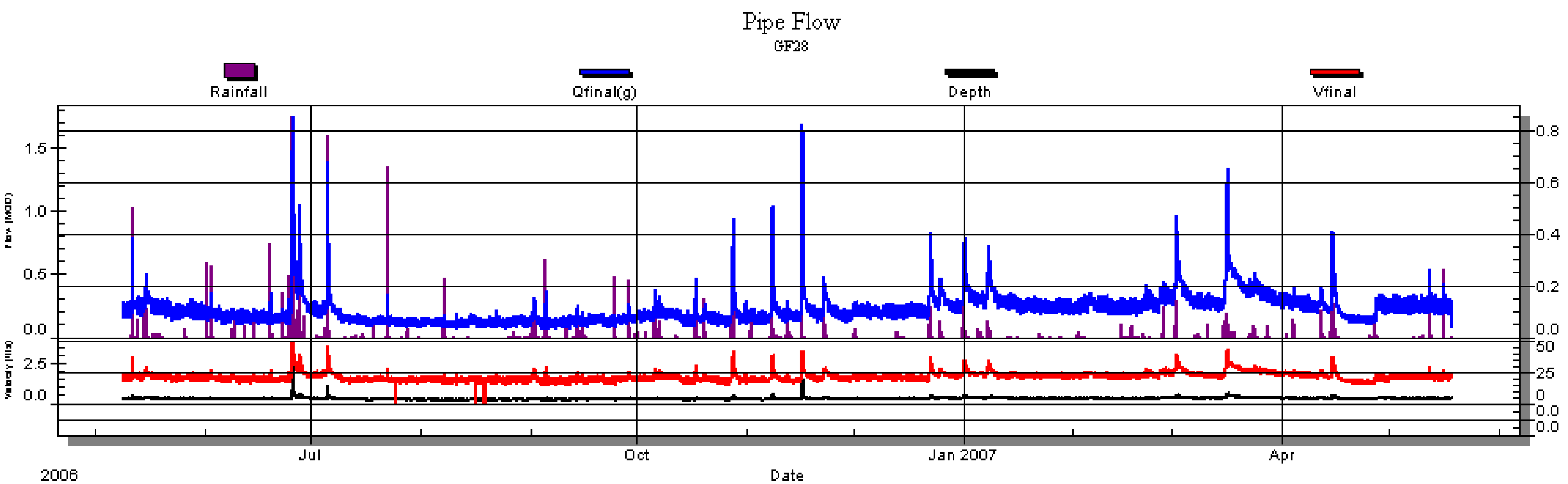

Pipe Flow
GF24
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date


Pipe Flow
GF25
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date

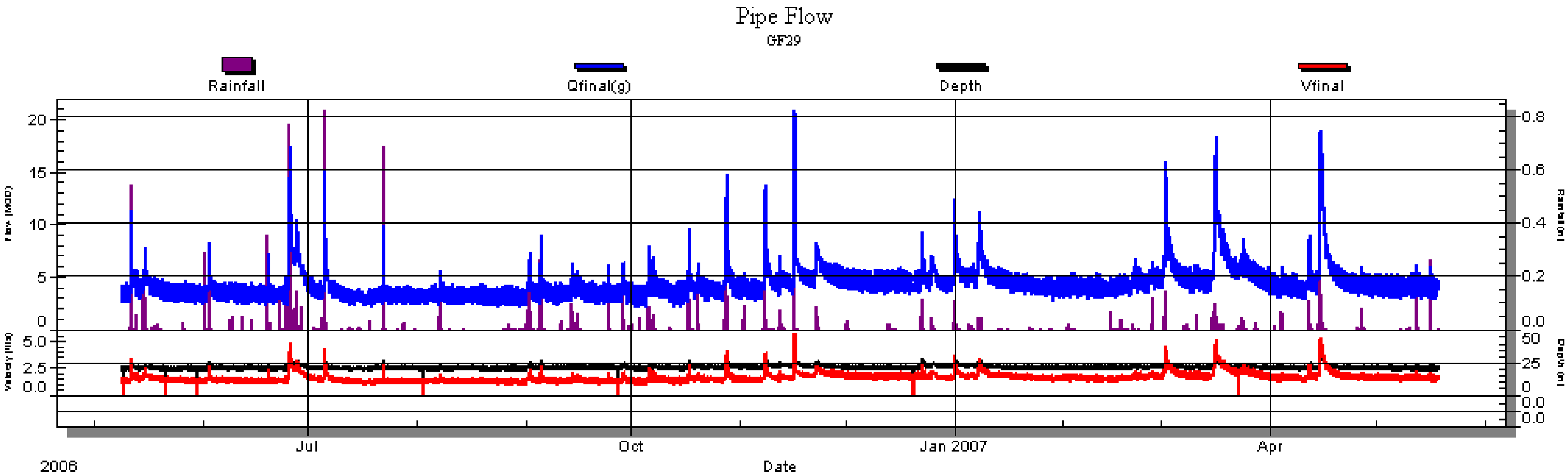

Pipe Flow
GF26
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date

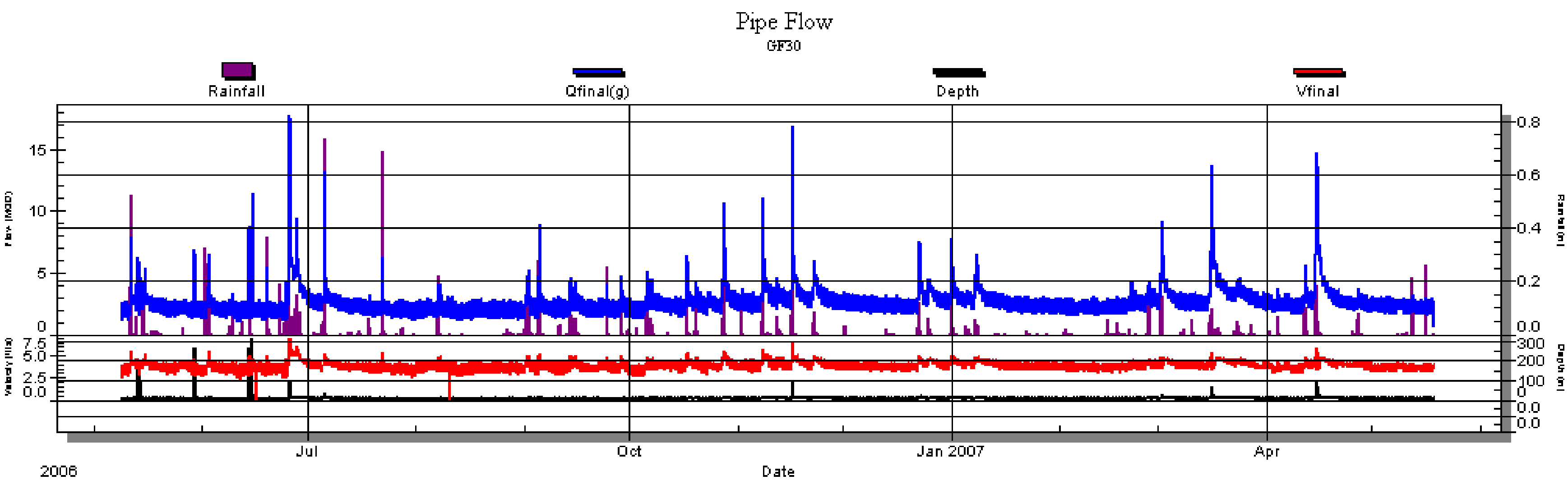


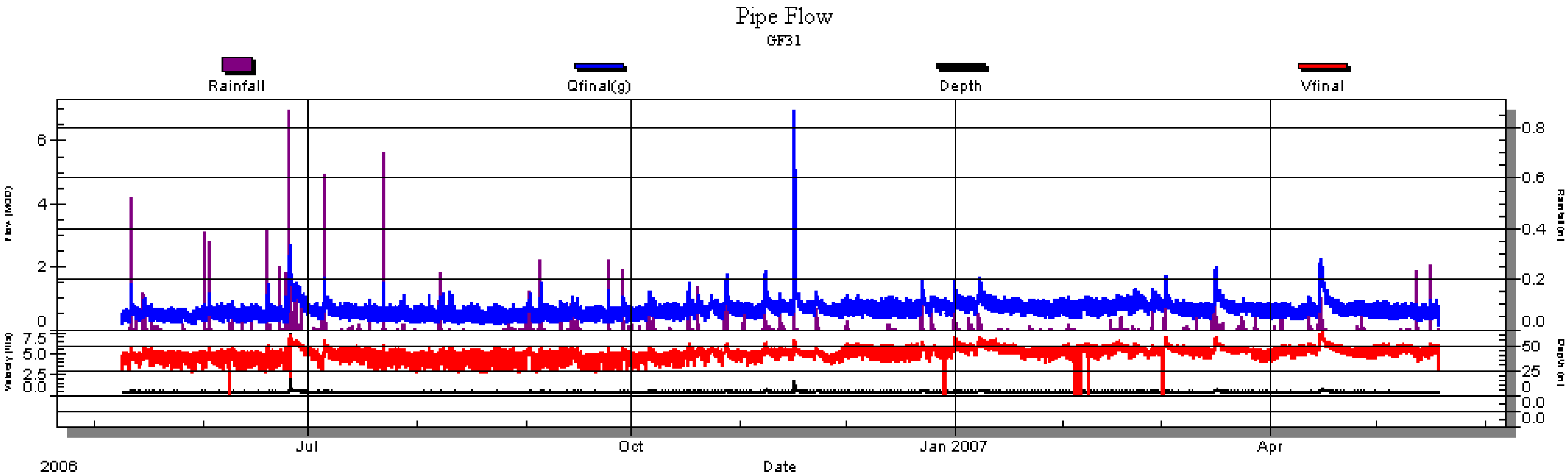
Pipe Flow
GF27
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date

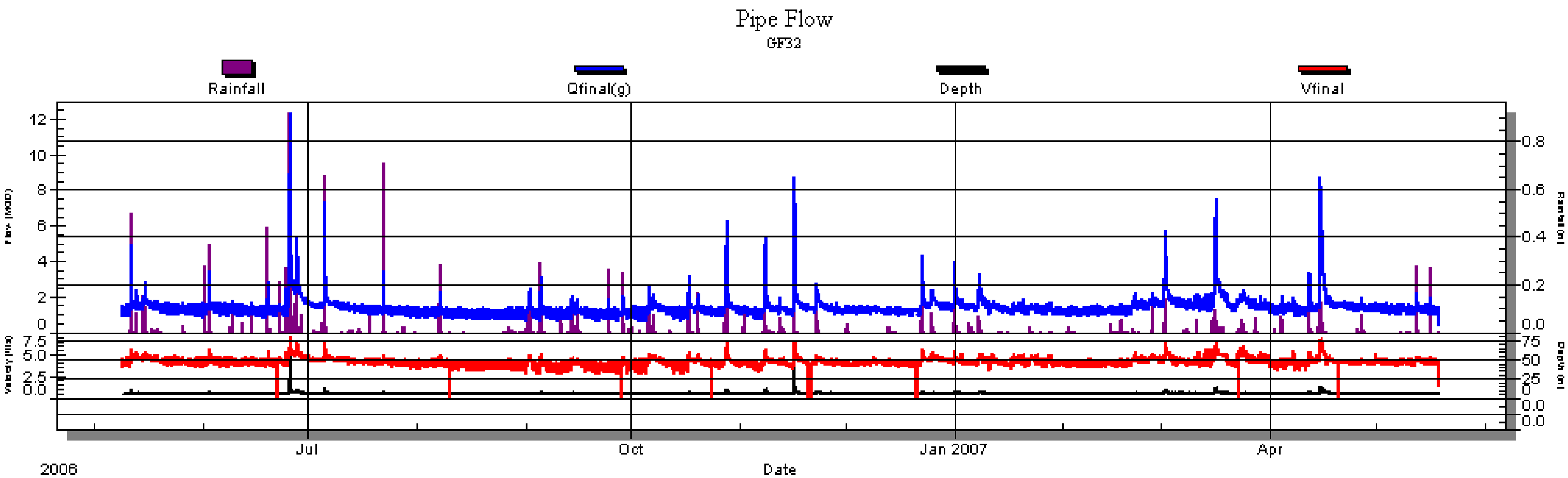


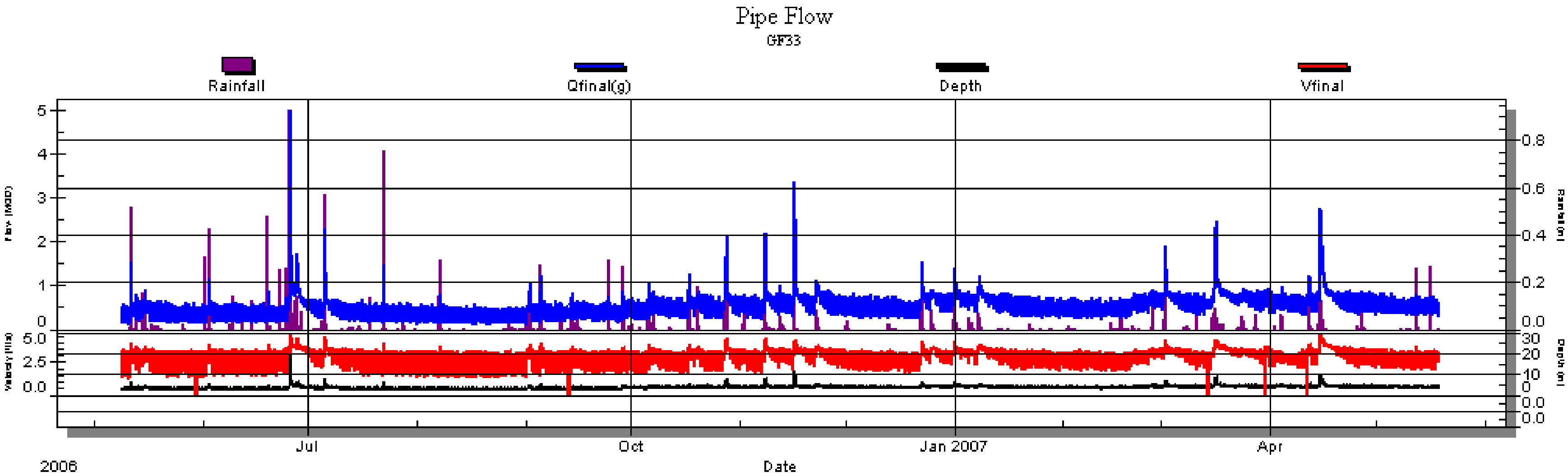
Pipe Flow
GF28
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date

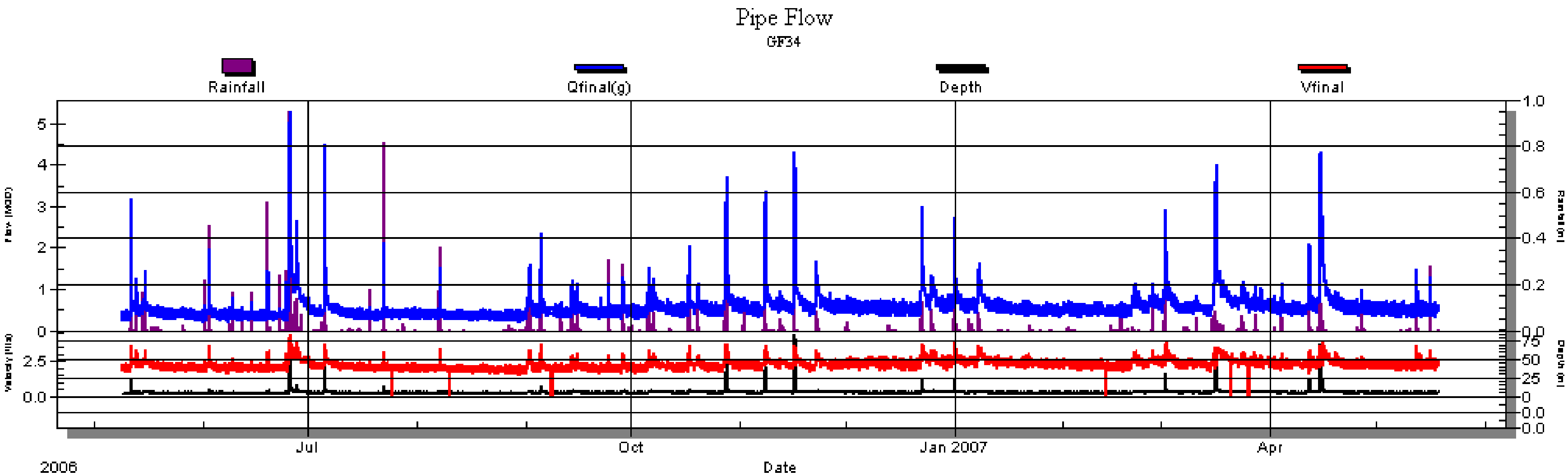

Pipe Flow
GF29
Rainfall
Qfinal(g)
Depth
Vfinal
20
15
10
5
0
5.0
2.5
0.0
0.8
0.6
0.4
0.2
0.0
50
25
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date

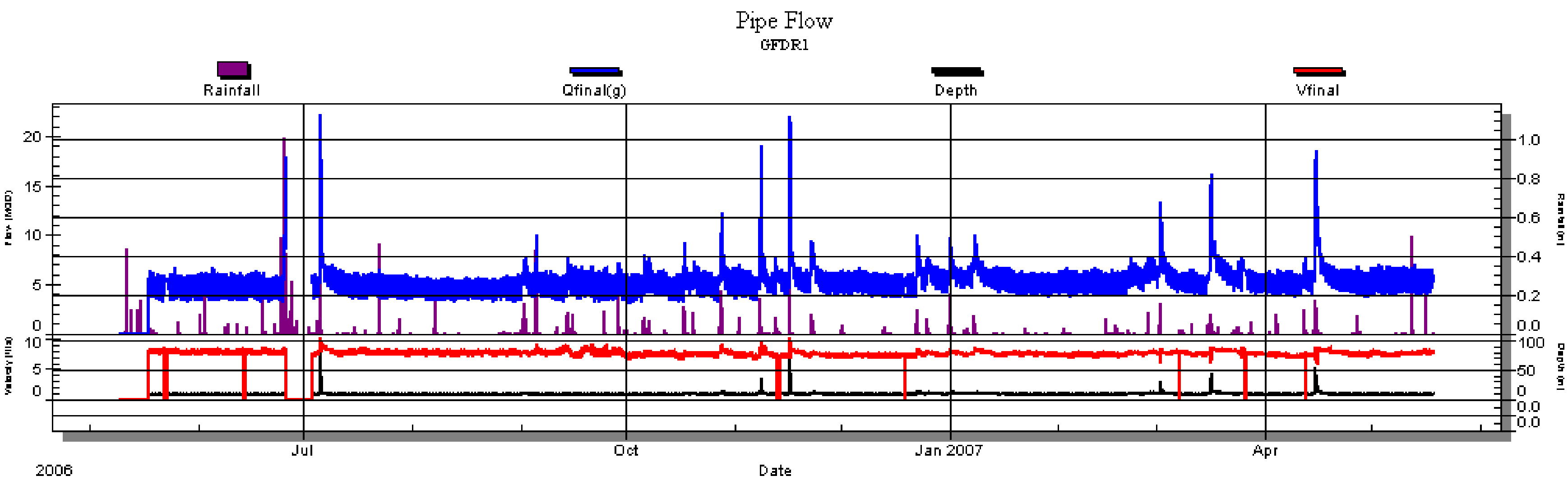

Pipe Flow
GF30
Rainfall
Qfinal(g)
Depth
Vfinal
15
10
5
0
7.5
5.0
2.5
0.0
0.8
0.6
0.4
0.2
0.0
300
200
100
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date

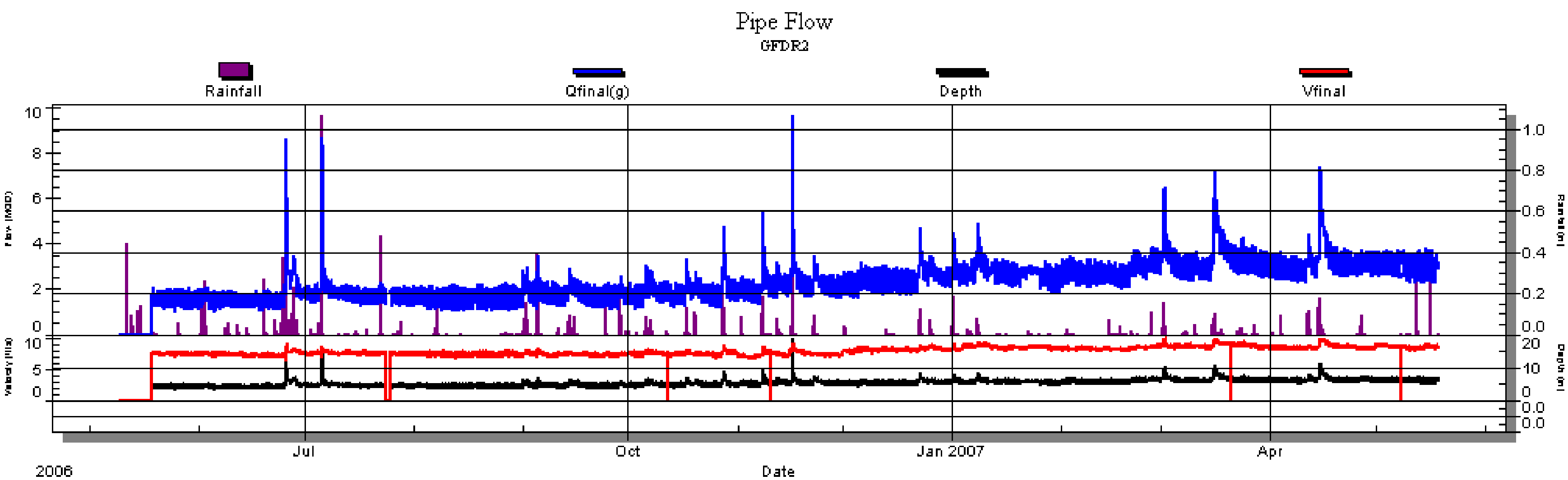

Pipe Flow
GF31
Rainfall
Qfinal(g)
Depth
Vfinal
Flow (MGD)
Velocity (ft/s)
Rainfall (in)
Depth (in)
Jul
Oct
Jan 2007
Apr
2006
Date

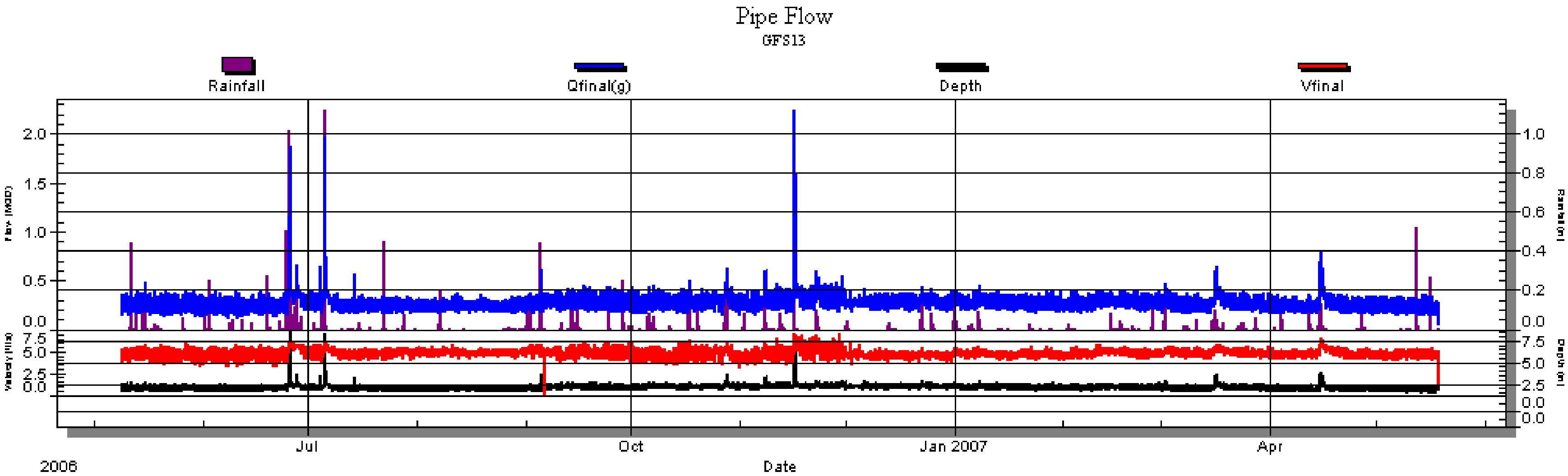

Pipe Flow
GF32
Rainfall
Qfinal(g)
Depth
Vfinal
Flow (MGD)
Velocity (ft/s)
Rainfall (in)
Depth (in)
Jul
Oct
Jan 2007
Apr
2006
Date

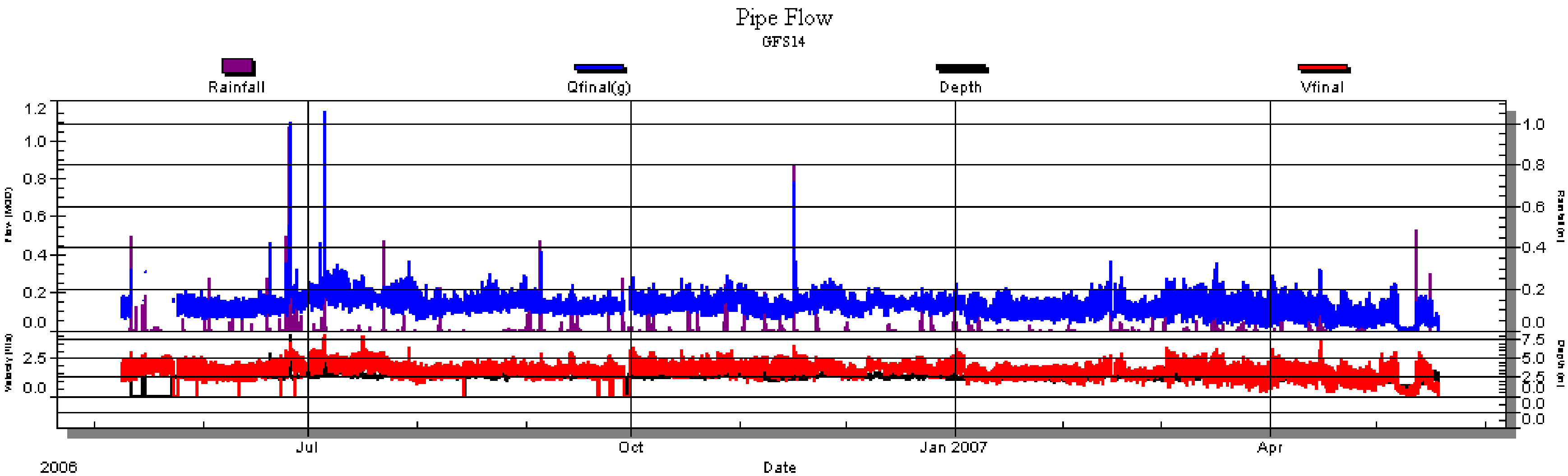

Pipe Flow
GF33
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date

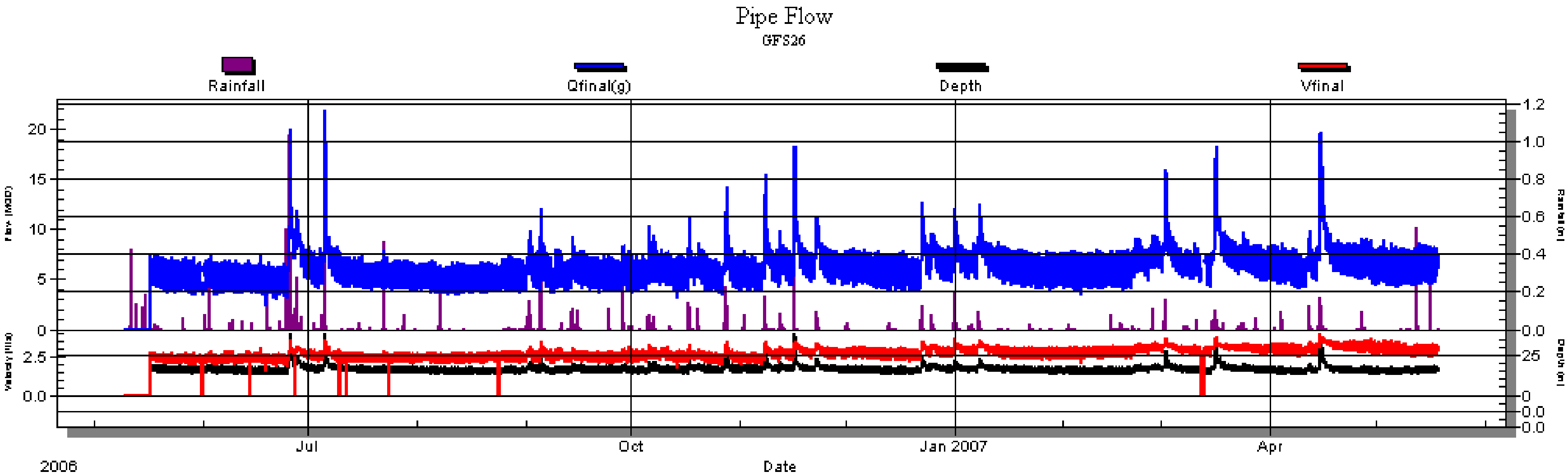

Pipe Flow
GF34
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date

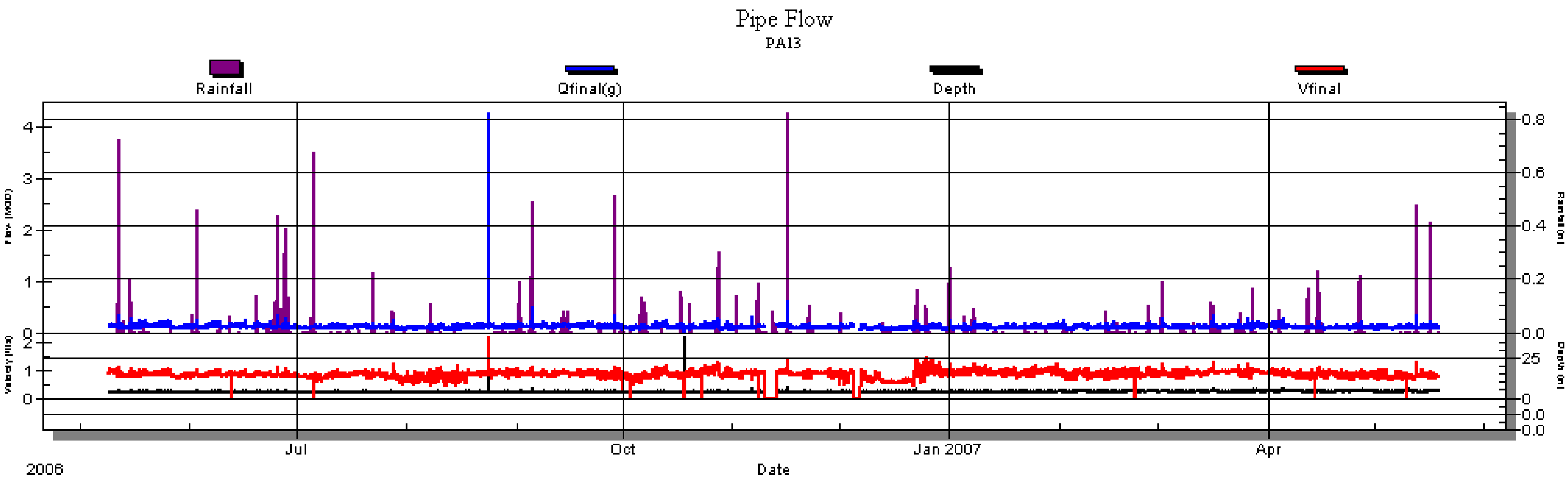

Pipe Flow
GFDR1
Rainfall
Qfinal(g)
Depth
Vfinal
20
15
10
5
0
10
5
0
1.0
0.8
0.6
0.4
0.2
0.0
100
50
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date

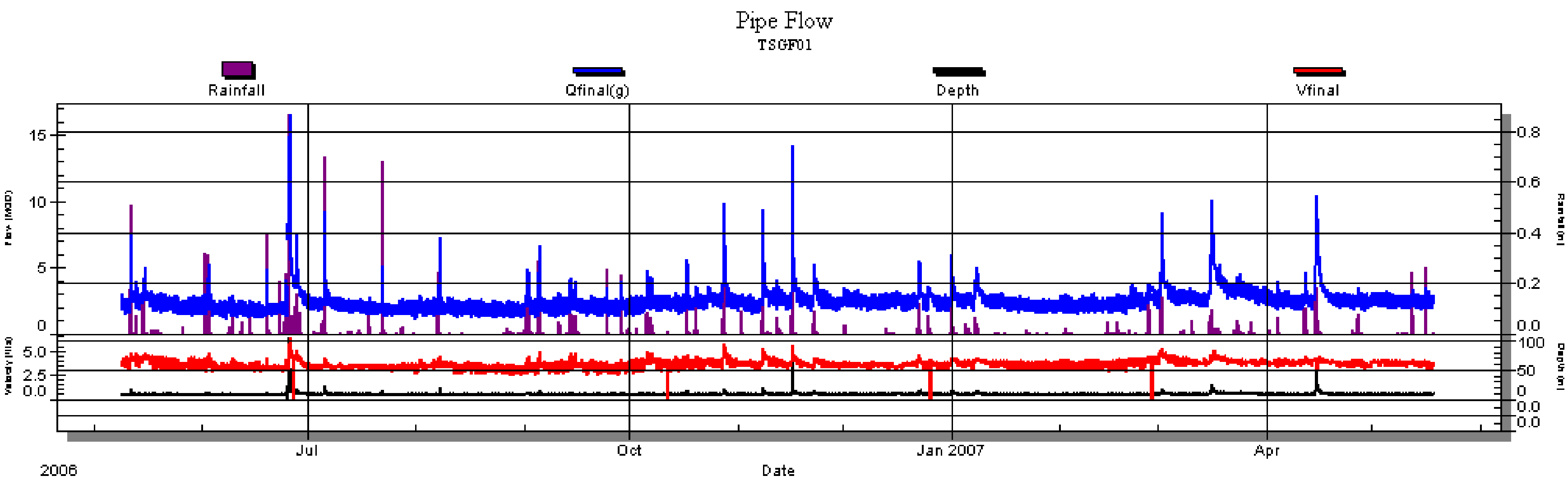

Pipe Flow
GFDR2
Rainfall
Qfinal(g)
Depth
Vfinal
10
8
6
4
2
0
10
5
0
1.0
0.8
0.6
0.4
0.2
0.0
20
10
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date

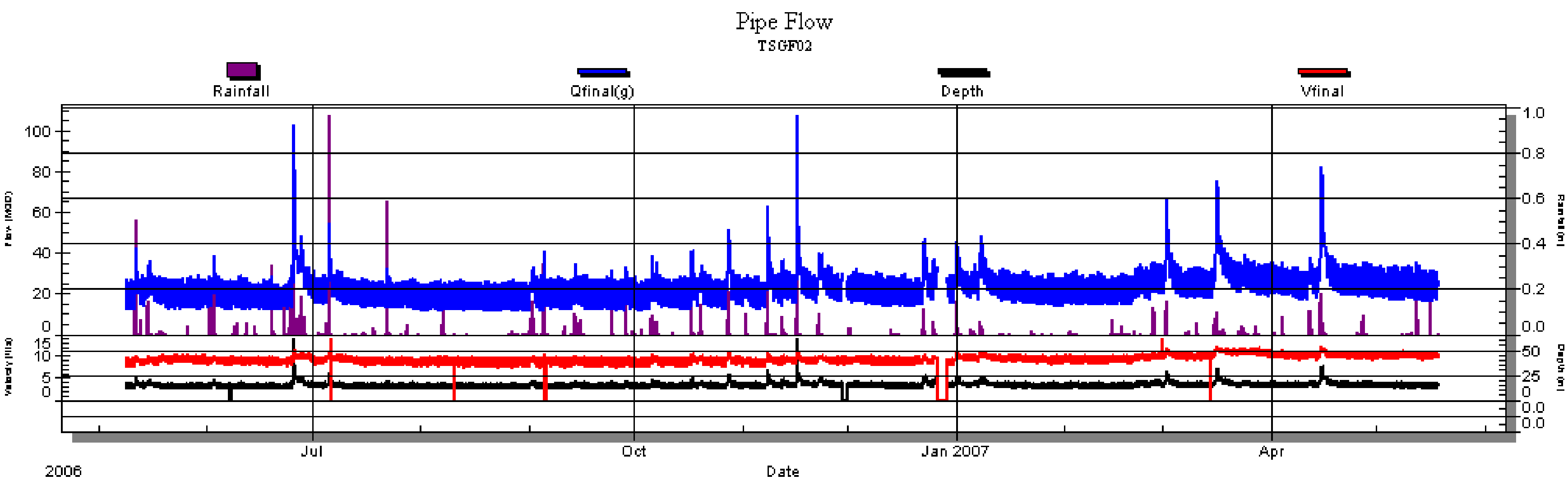

Pipe Flow
GFS13
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date

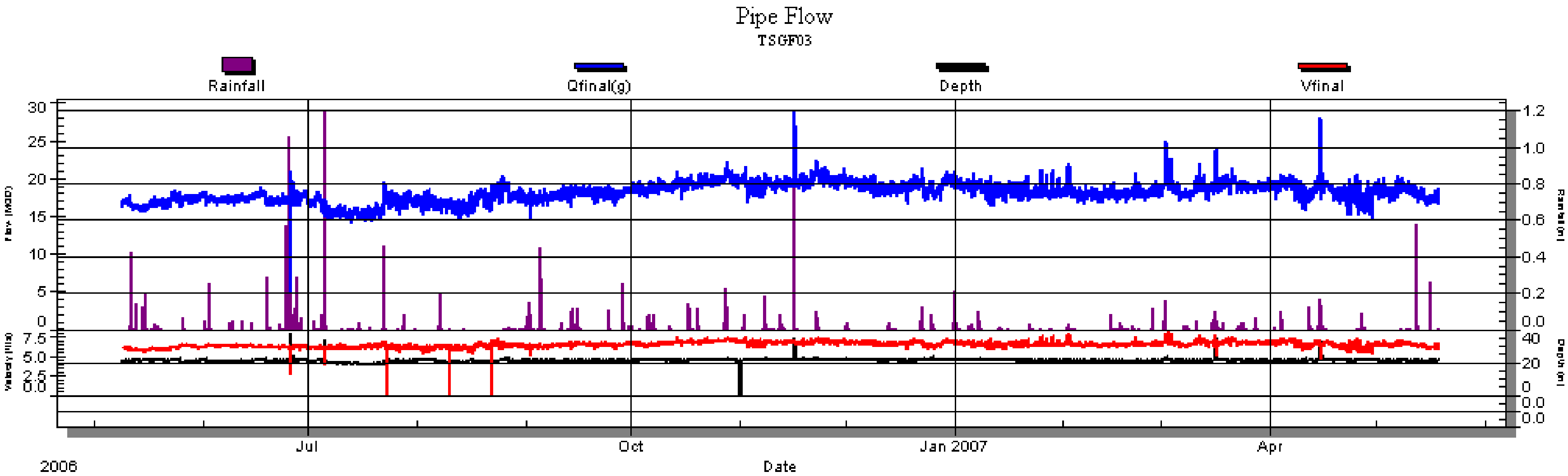

Pipe Flow
GFS14
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date


Pipe Flow
GFS26
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date

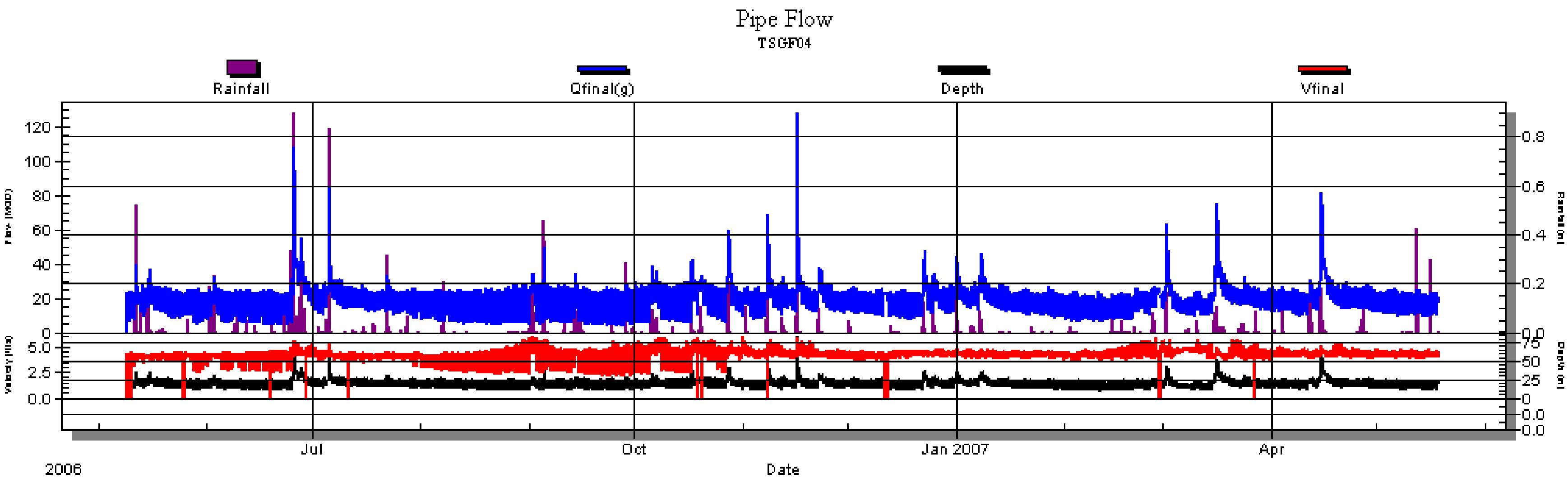

Pipe Flow
PA13
Rainfall
Qfinal(g)
Depth
Vfinal
Jul
Oct
Jan 2007
Apr
2006
Date


Pipe Flow
TSGF01
Rainfall
Qfinal(g)
Depth
Vfinal
15
10
5
0
5.0
2.5
0.0
0.8
0.6
0.4
0.2
0.0
100
50
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date

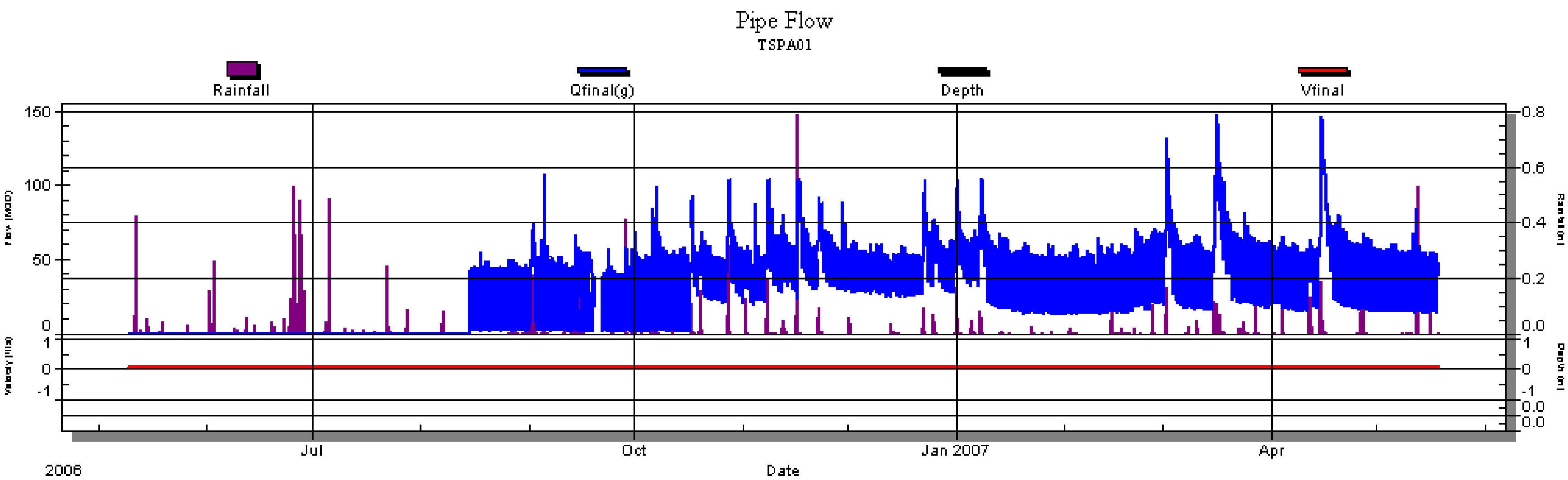

Pipe Flow
TSGF02
Rainfall
Qfinal(g)
Depth
Vfinal
100
80
60
40
20
0
15
10
5
0
1.0
0.8
0.6
0.4
0.2
0.0
50
25
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date

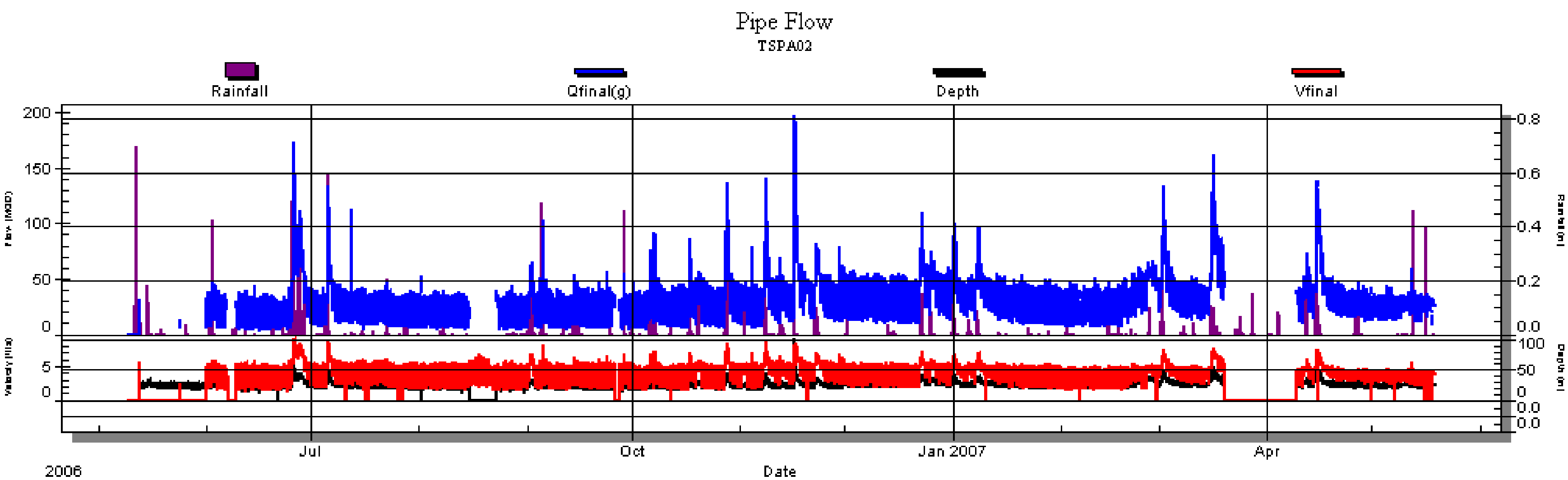


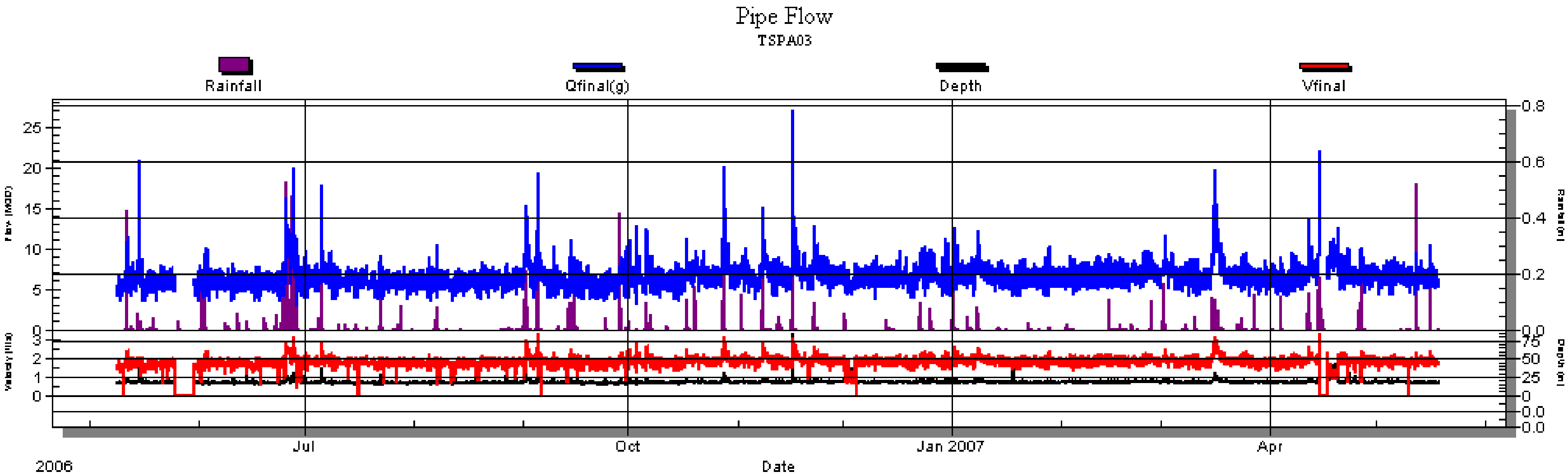
Pipe Flow
TSGF03
Rainfall
Qfinal(g)
Depth
Vfinal
30
25
20
15
10
5
0
7.5
5.0
2.5
0.0
1.2
1.0
0.8
0.6
0.4
0.2
0.0
40
20
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date



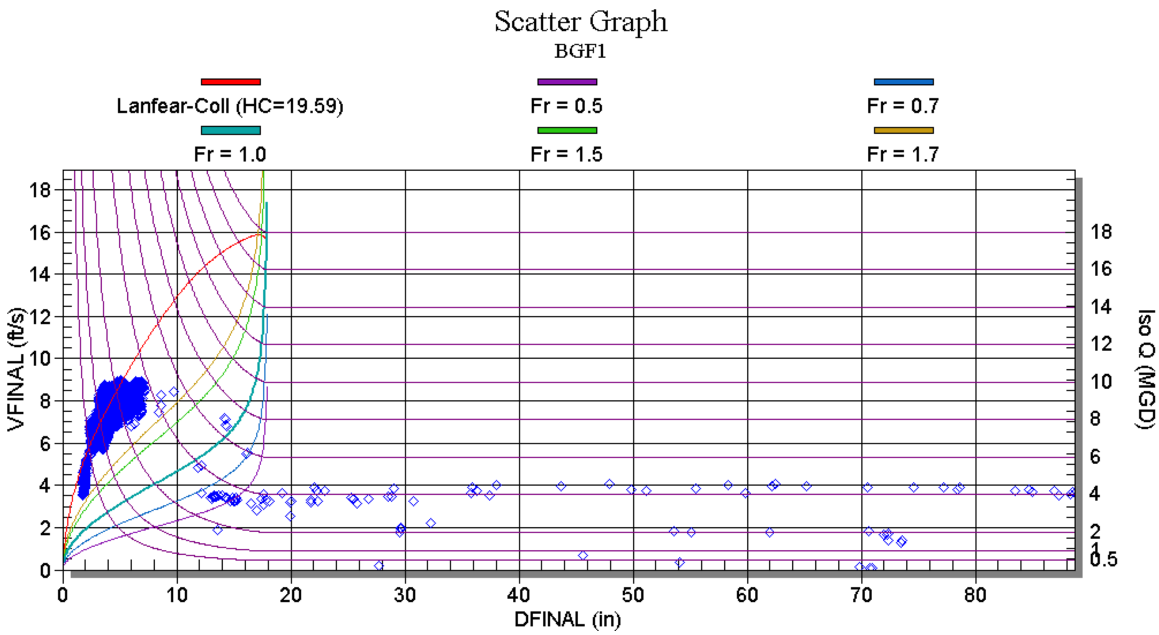
Pipe Flow
TSGF04
Rainfall
Qfinal(g)
Depth
Vfinal
120
100
80
60
40
20
0
5.0
2.5
0.0
0.8
0.6
0.4
0.2
0.0
75
50
25
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date

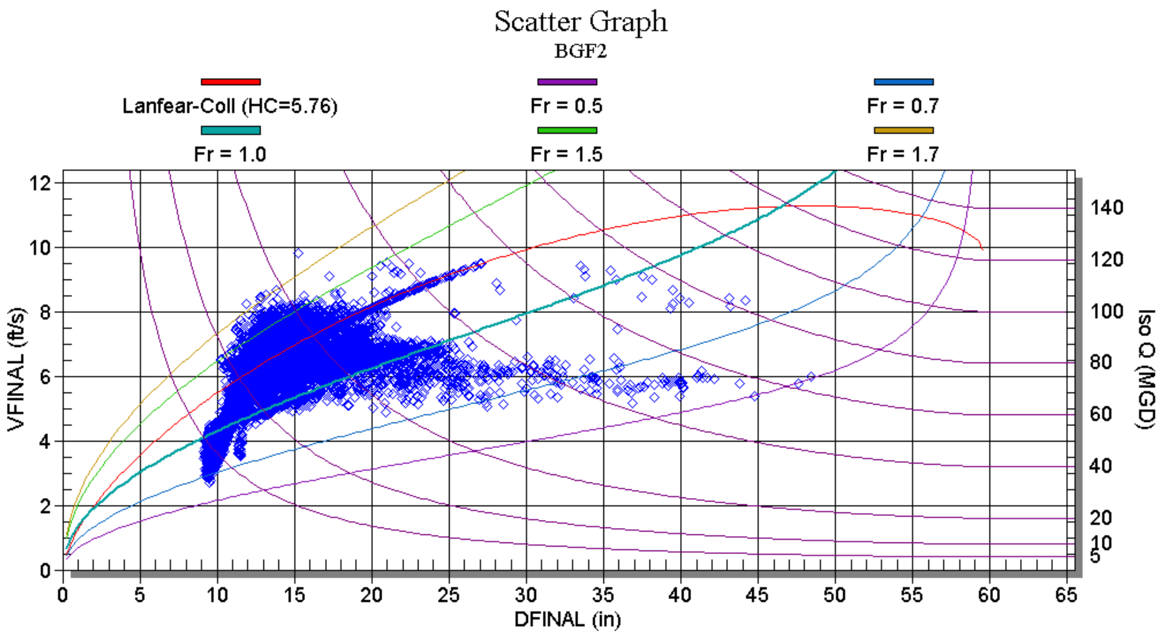

Pipe Flow
TSPA01
Rainfall
Qfinal(g)
Depth
Vfinal
Flow (MGD)
Velocity (ft/s)
Rainfall (in)
Depth (in)
Jul
Oct
Jan 2007
Apr
2006
Date


Pipe Flow
TSPA02
Rainfall
Qfinal(g)
Depth
Vfinal
Flow (MGD)
Velocity (ft/s)
Rainfall (in)
Depth (in)
Jul
Oct
Jan 2007
Apr
2006
Date

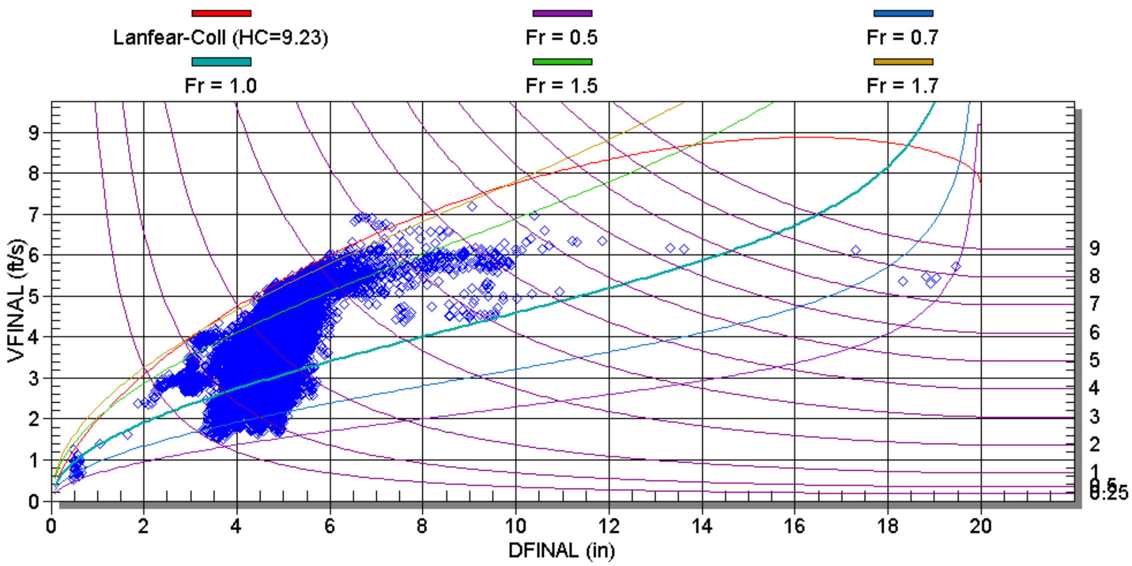


Pipe Flow
TSPA03
Rainfall
Qfinal(g)
Depth
Vfinal
25
20
15
10
5
0
3
2
1
0
0.8
0.6
0.4
0.2
0.0
.75
.50
.25
0
0.0
0.0
Jul
Oct
Jan 2007
Apr
2006
Date

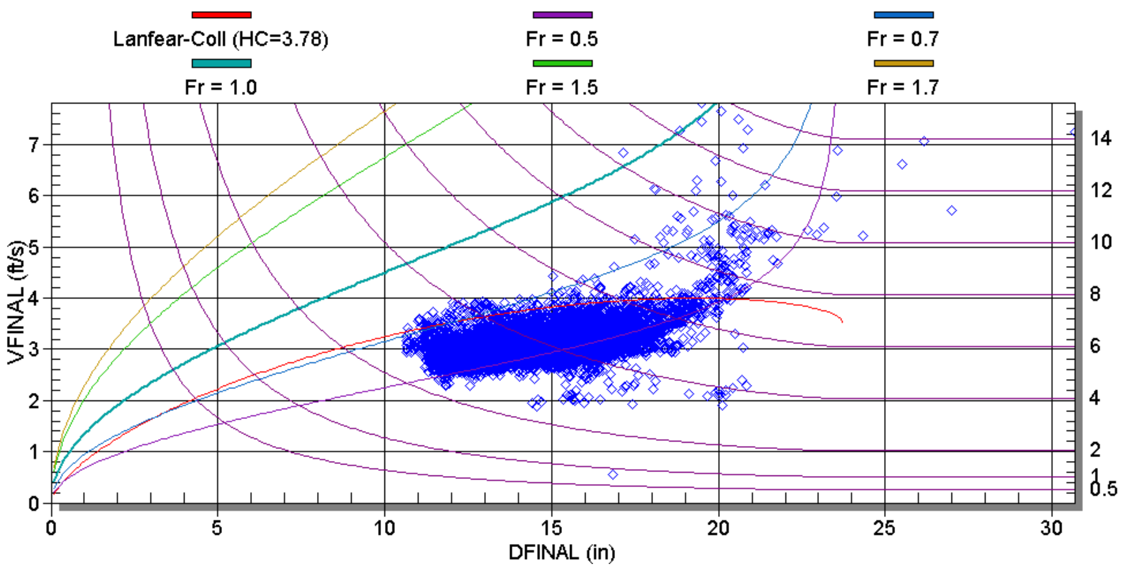

Scatter Graph
BGF1
Lanfear-Coll (HC=19.59)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)


Scatter Graph
BGF2
Lanfear-Coll (HC=5.76)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

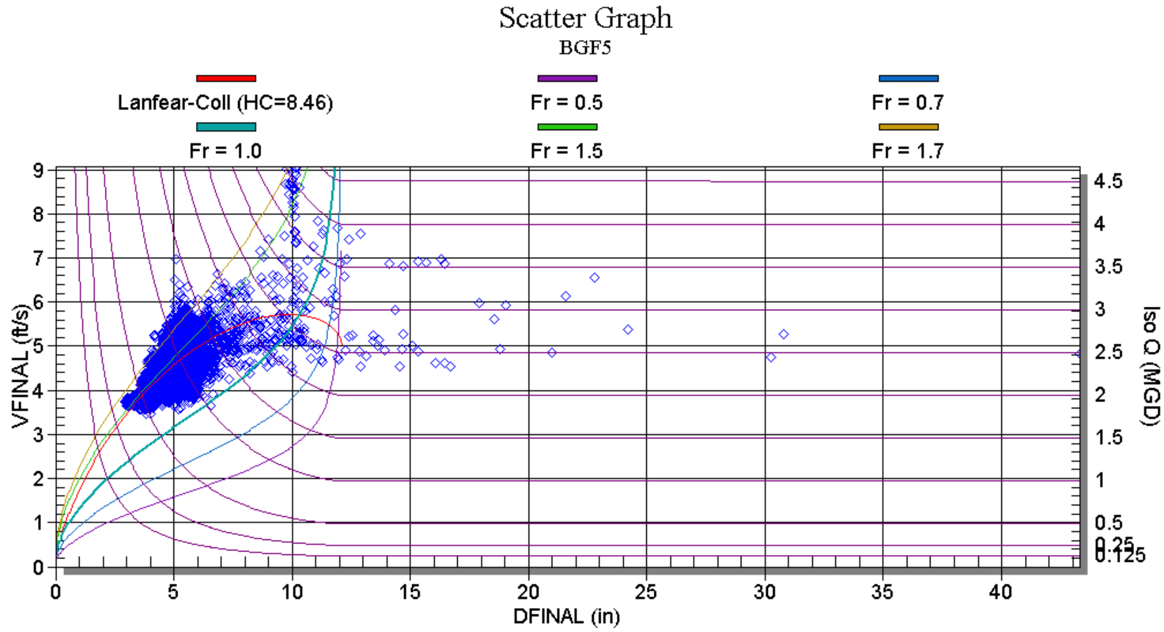
Scatter Graph
BGF3



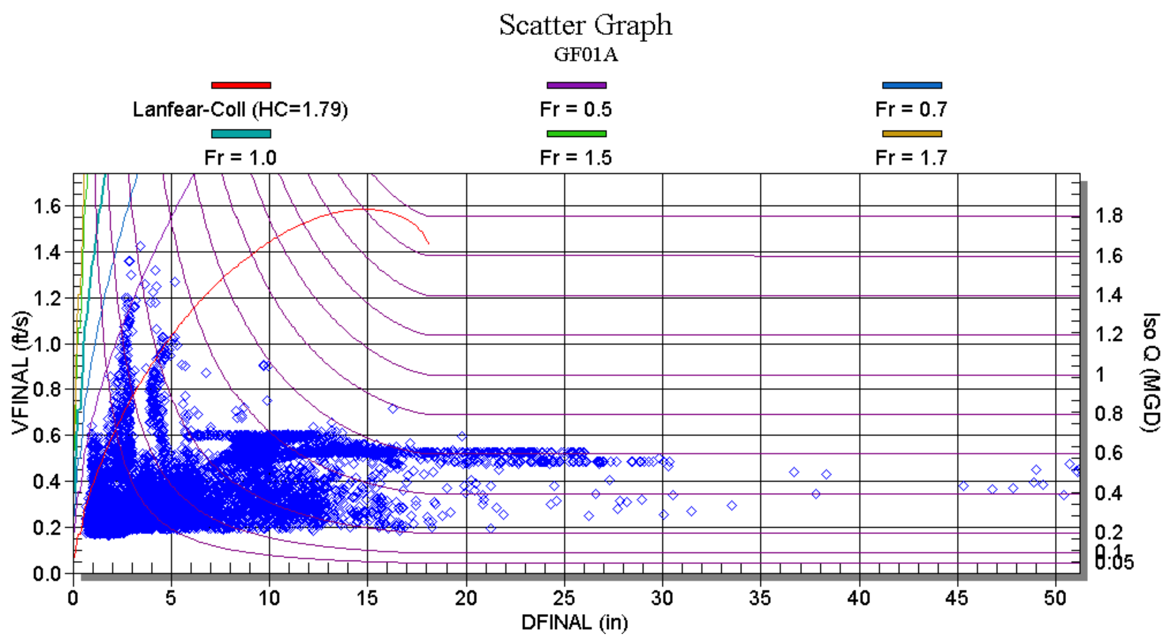
Scatter Graph
BGF4



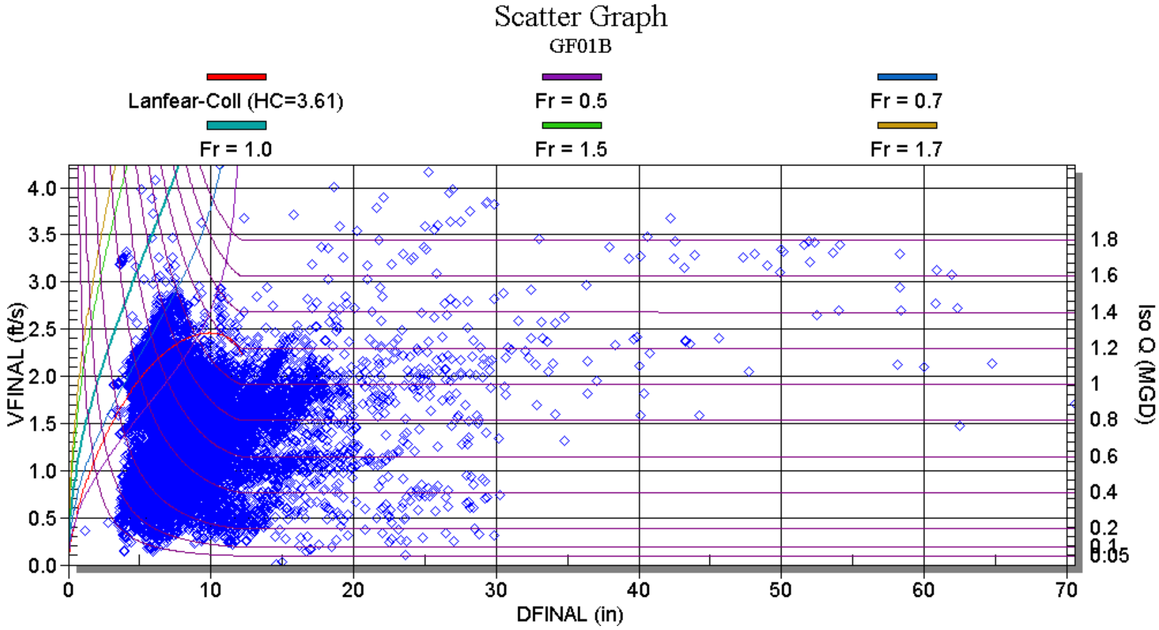
Appendix 3-2

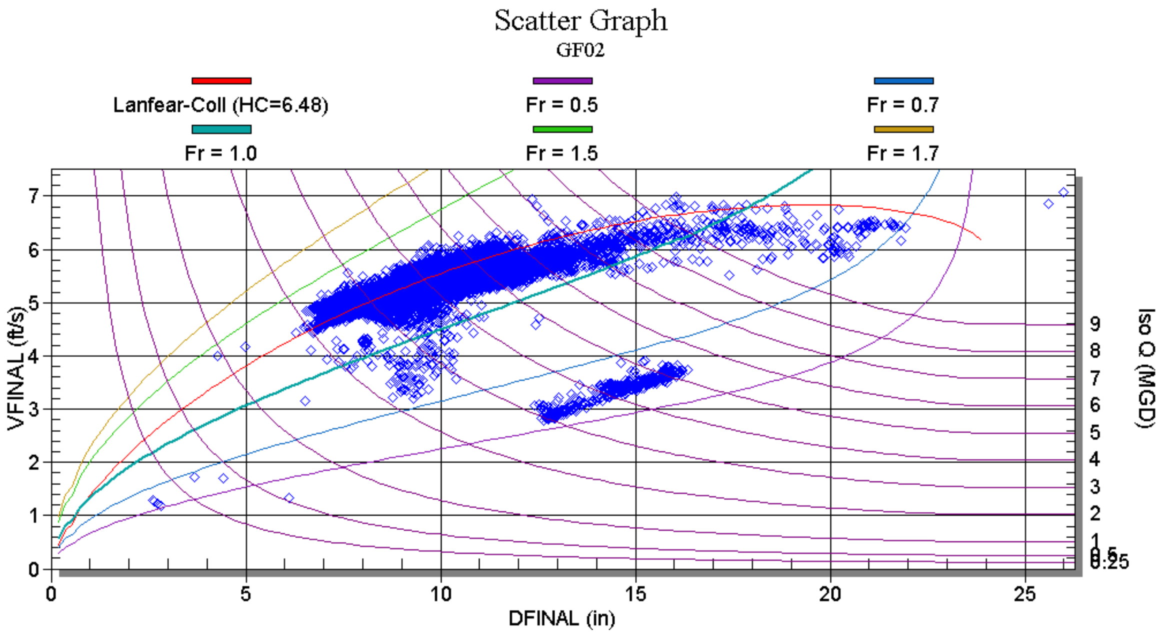


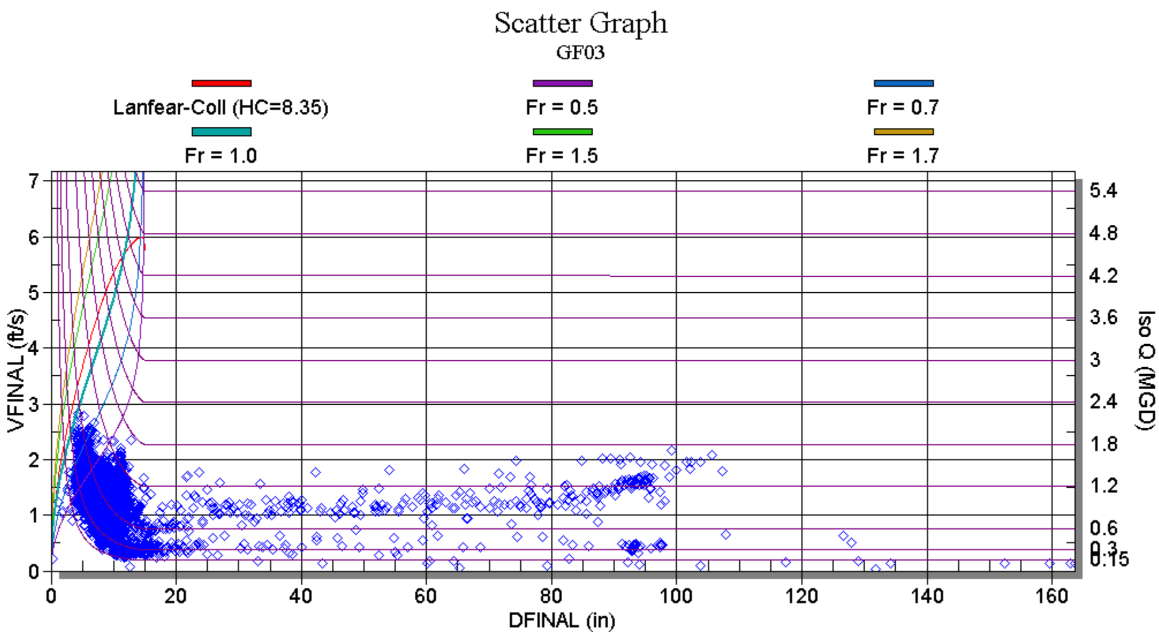
Scatter Graph
BGF5
Lanfear-Coll (HC=8.46)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

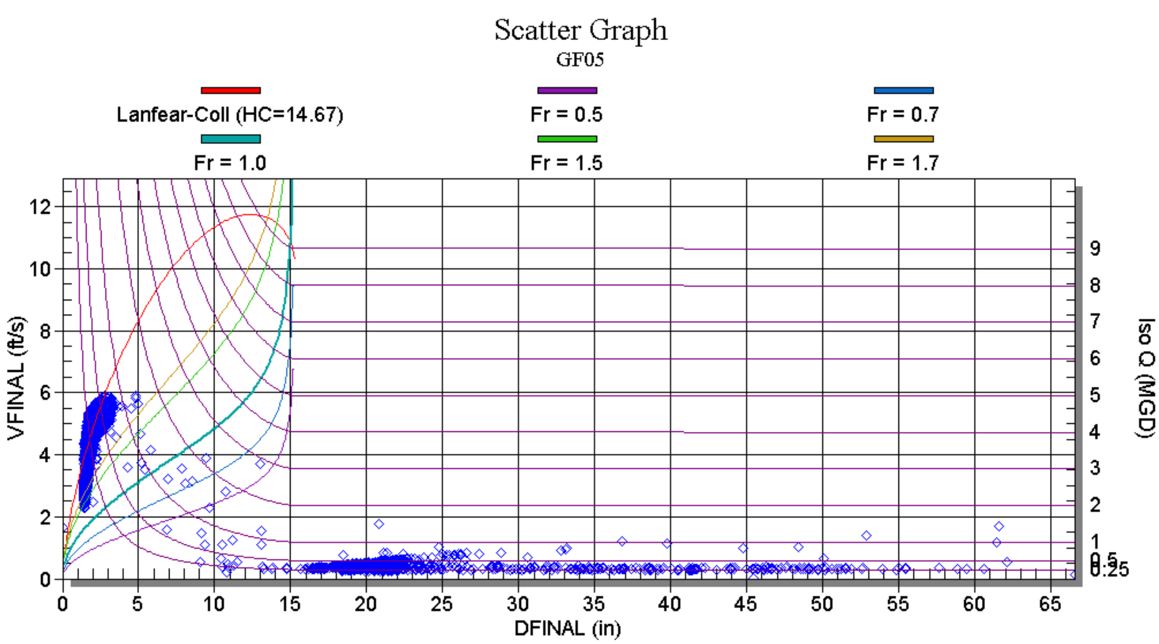


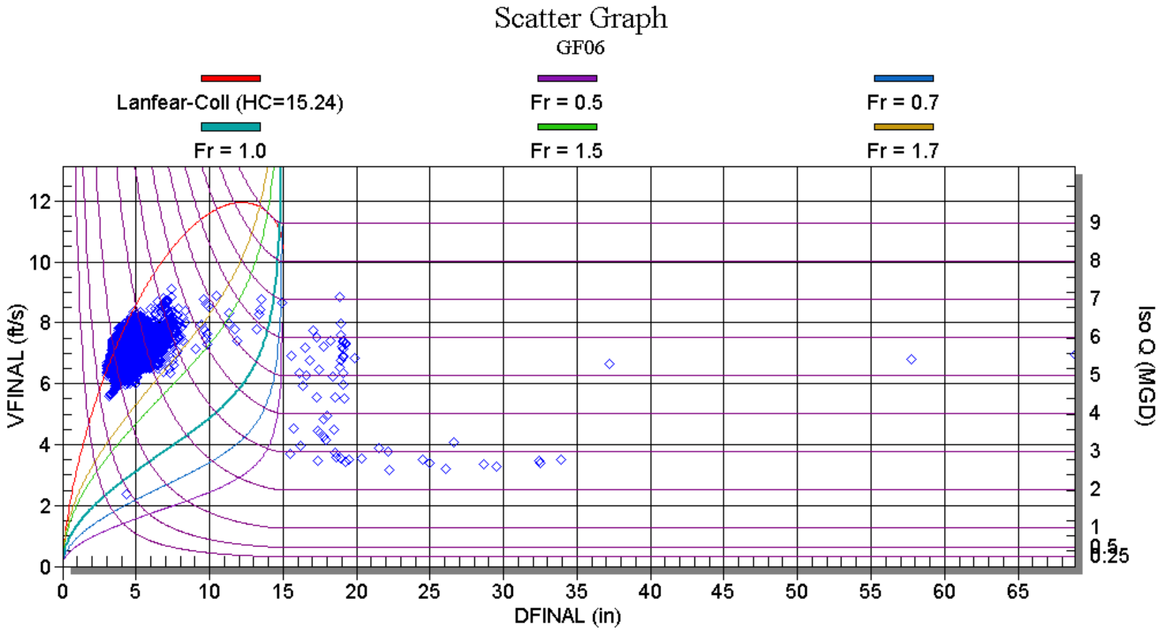
Scatter Graph
GF01A
Lanfear-Coll (HC=1.79)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

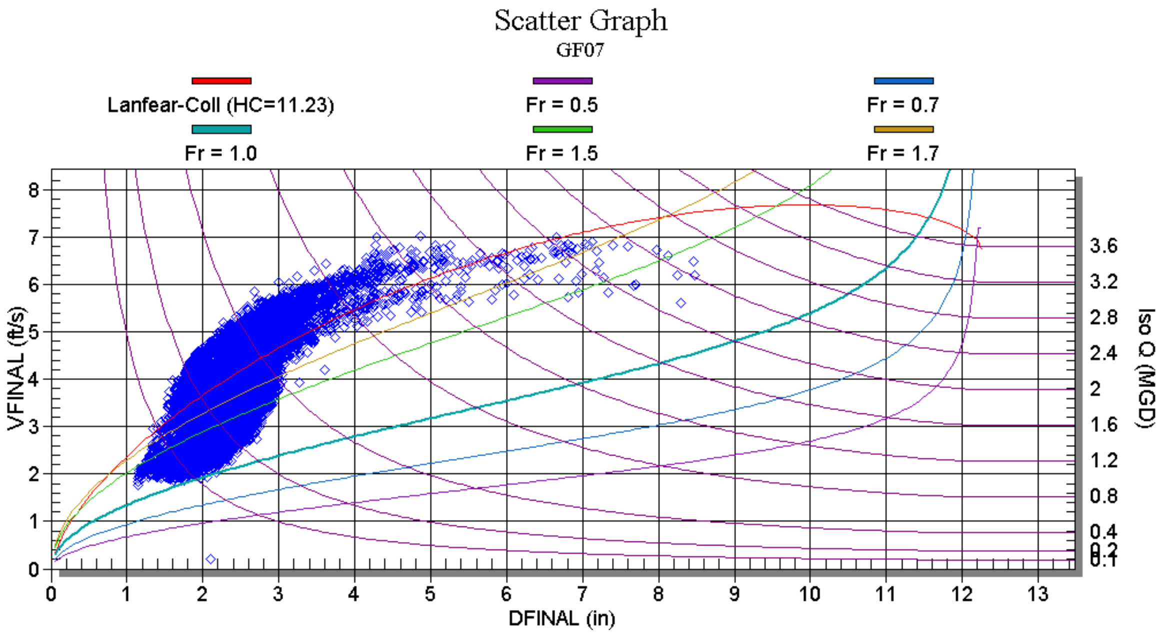

Scatter Graph
GF01B
Lanfear-Coll (HC=3.61)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

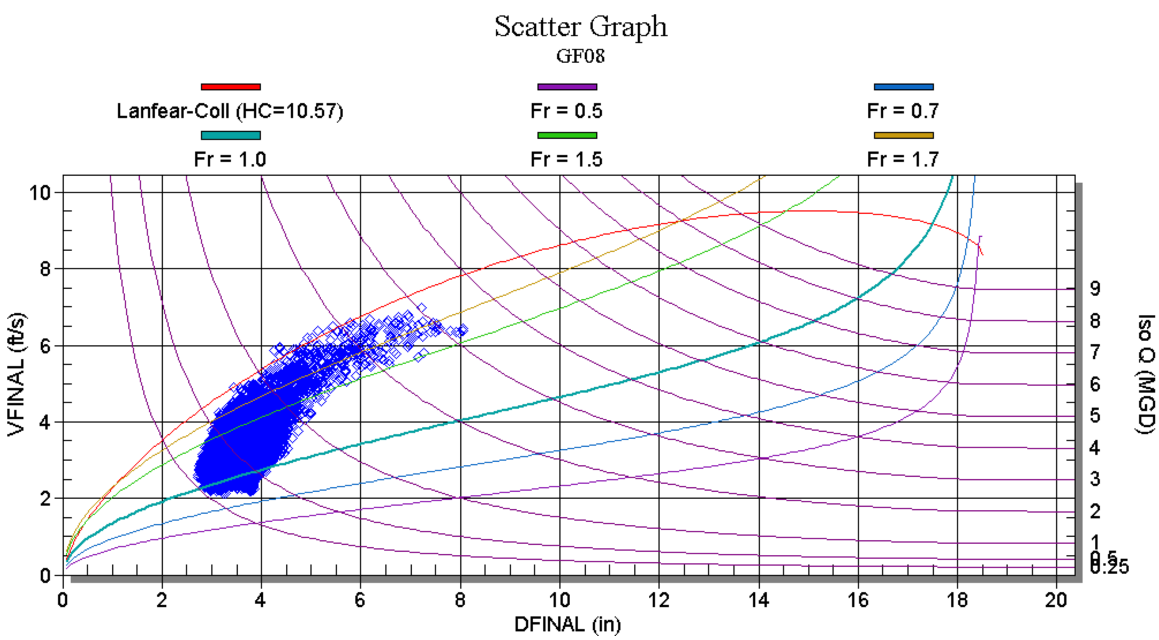

Scatter Graph
GF02
Lanfear-Coll (HC=6.48)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

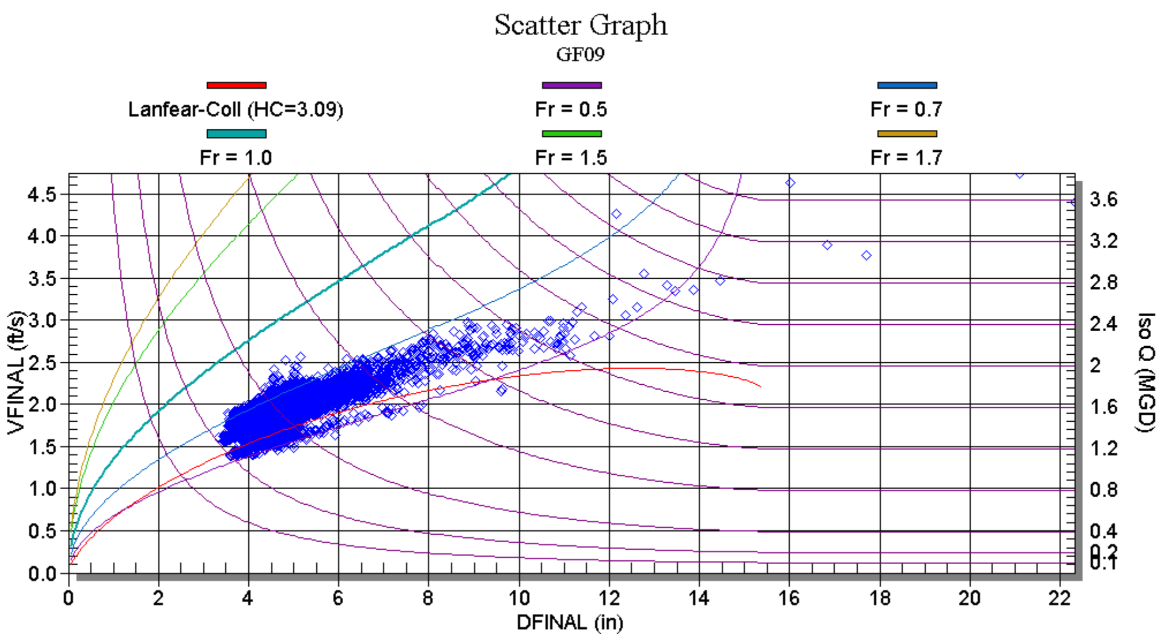

Scatter Graph
GF03
Lanfear-Coll (HC=8.35)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

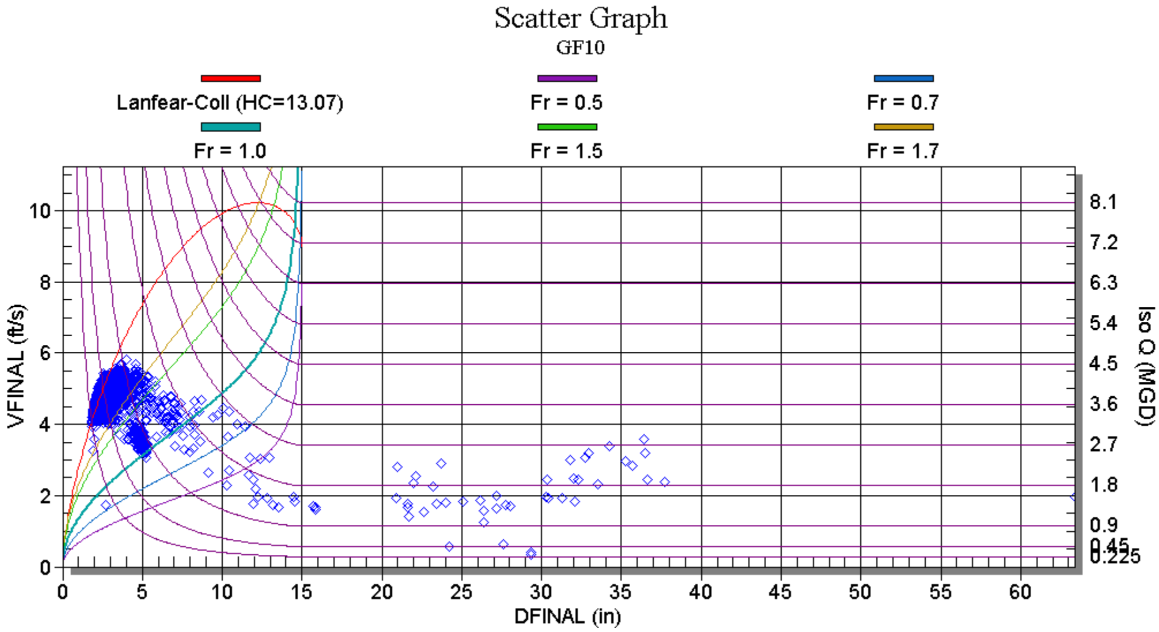

Scatter Graph
GF05
Lanfear-Coll (HC=14.67)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

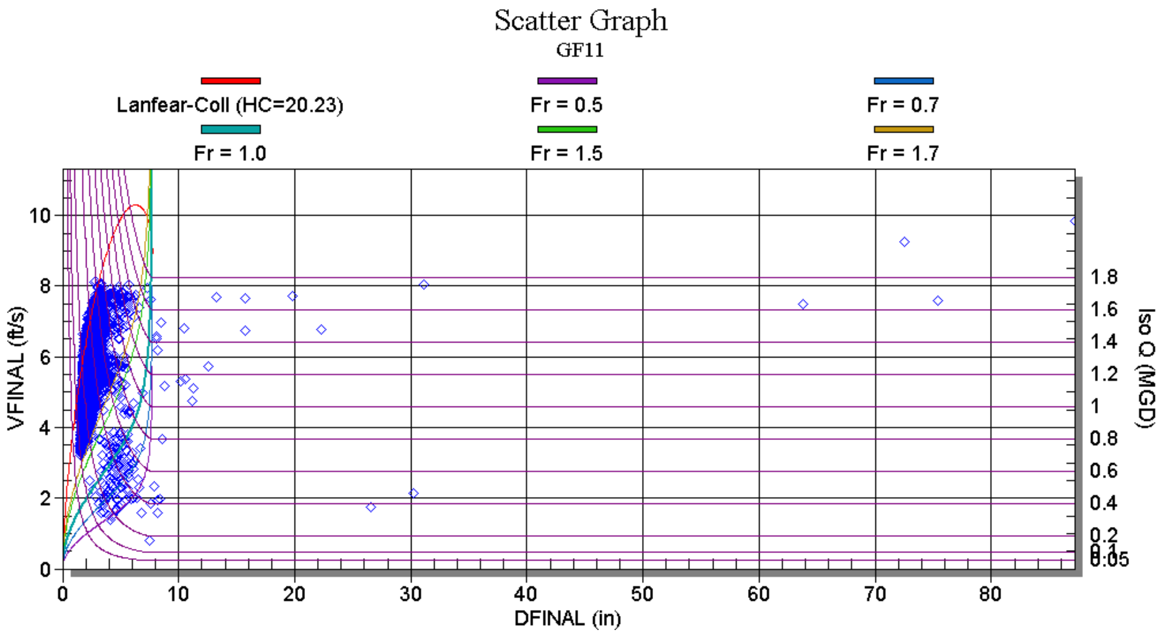

Scatter Graph
GF06
Lanfear-Coll (HC=15.24)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

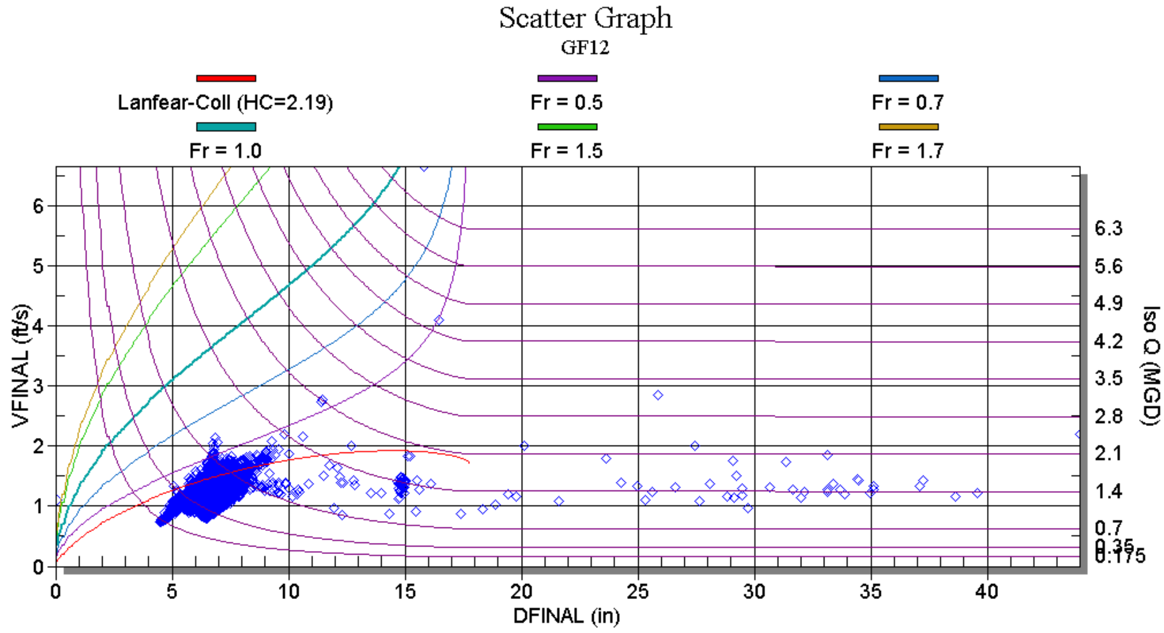

Scatter Graph
GF07
Lanfear-Coll (HC=11.23)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

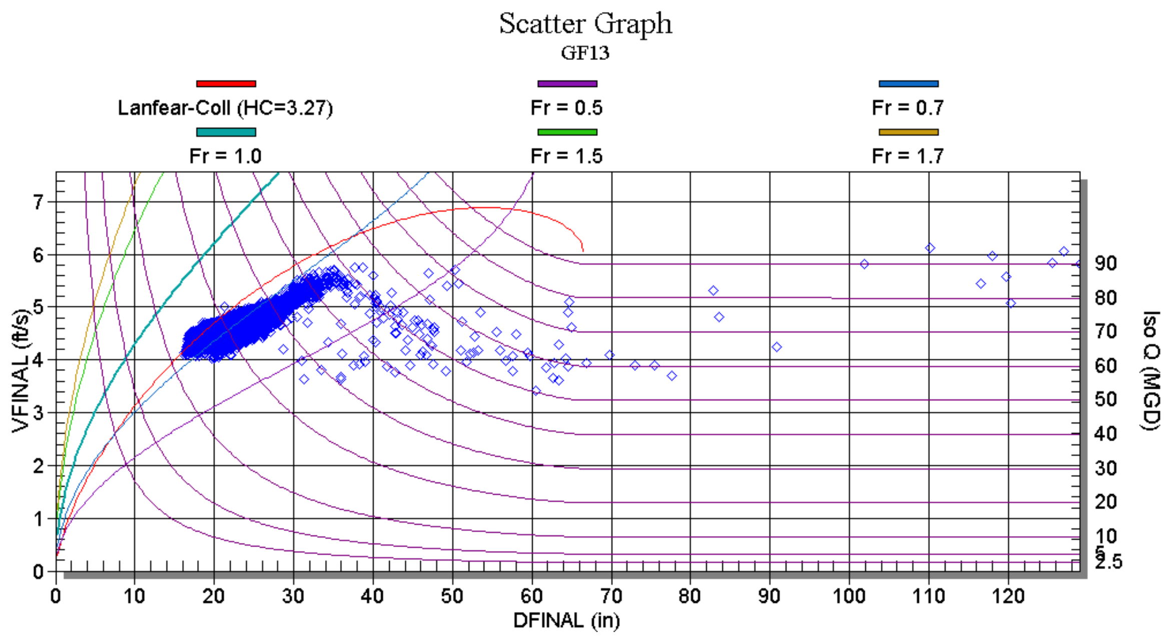

Scatter Graph
GF08
Lanfear-Coll (HC=10.57)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

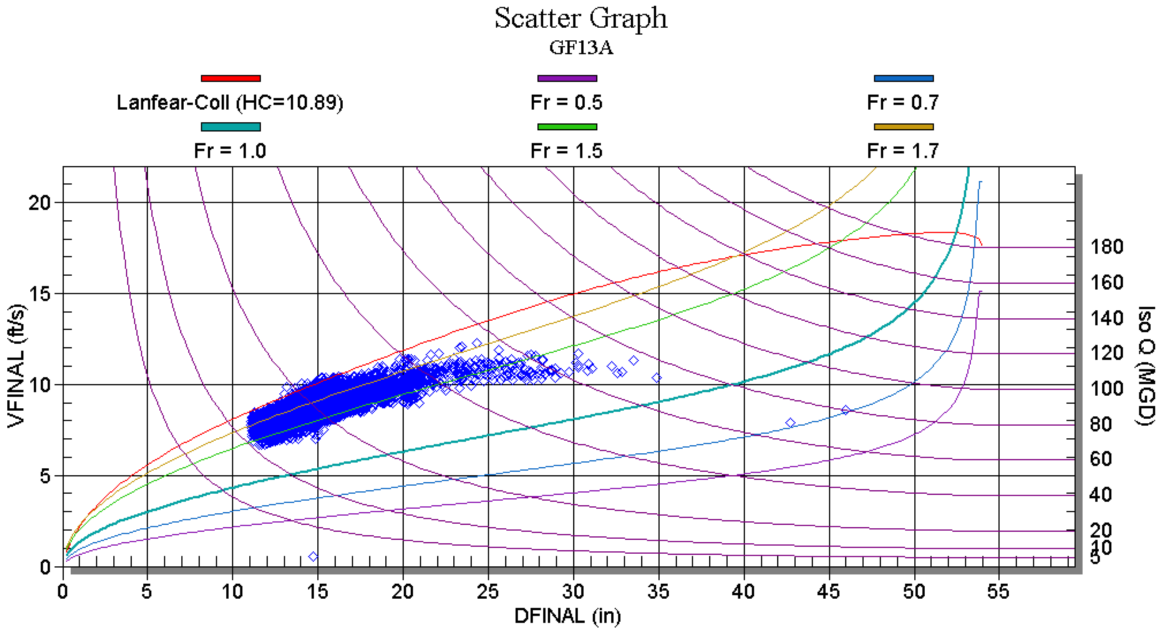

Scatter Graph
GF09
Lanfear-Coll (HC=3.09)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

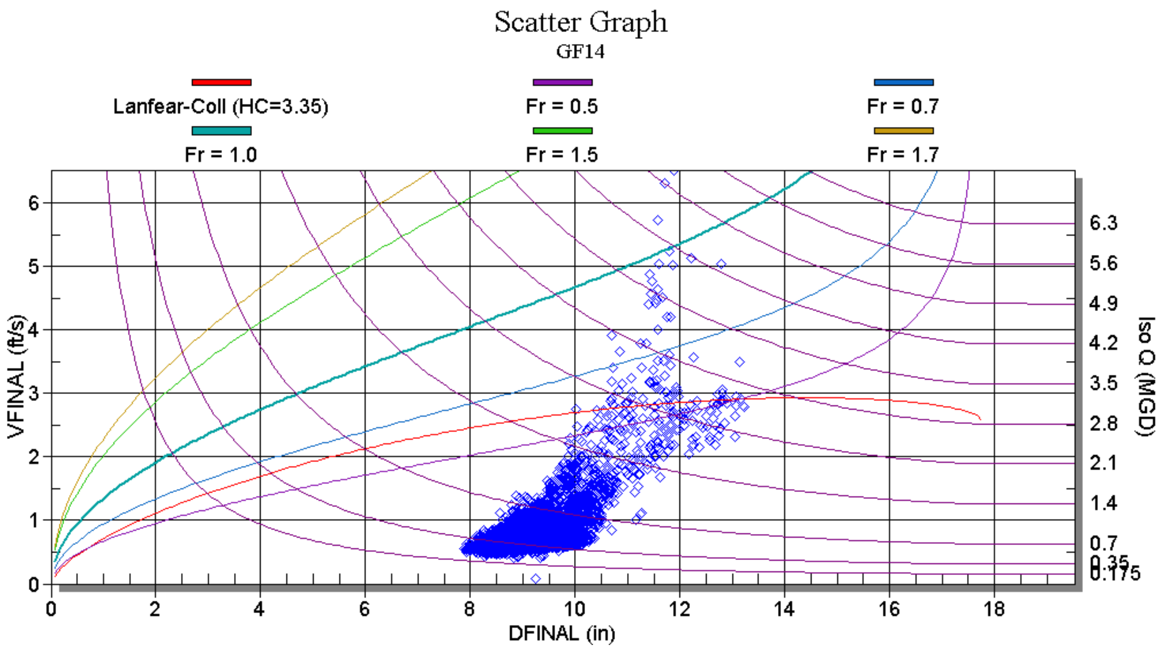

Scatter Graph
GF10
Lanfear-Coll (HC=13.07)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)
8.1
7.2
6.3
5.4
4.5
3.6
2.7
1.8
0.9
0.45
0.225

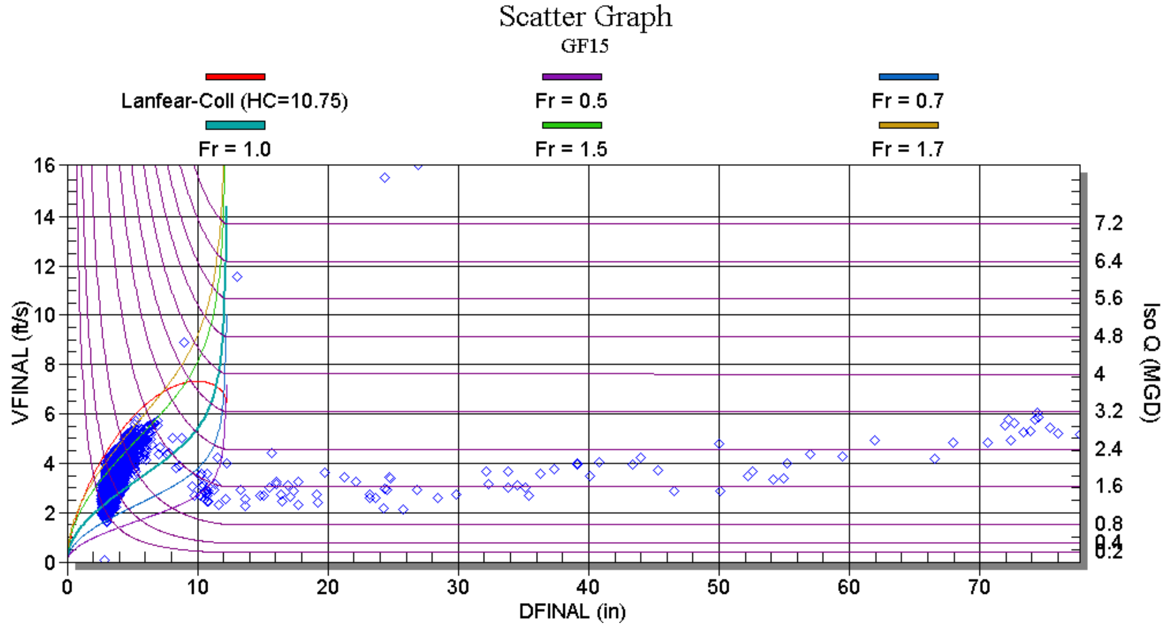

Scatter Graph
GF11
Lanfear-Coll (HC=20.23)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0.1
0.05


Scatter Graph
GF12
Lanfear-Coll (HC=2.19)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)
6.3
5.6
4.9
4.2
3.5
2.8
2.1
1.4
0.7
0.35
0.175

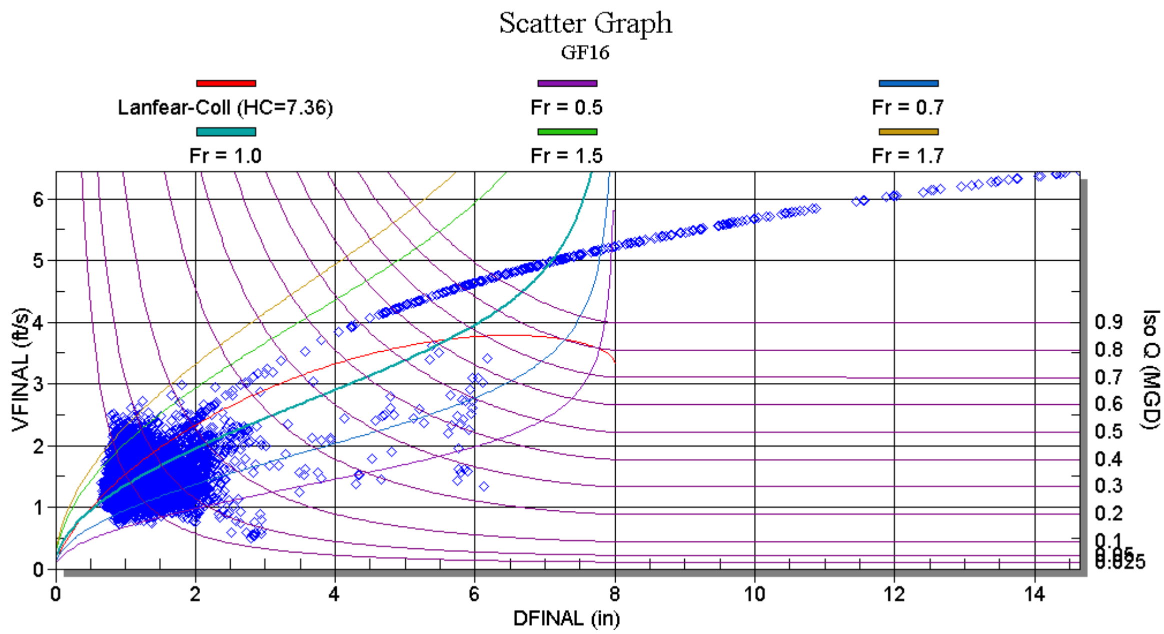

Scatter Graph
GF13
Lanfear-Coll (HC=3.27)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)
90
80
70
60
50
40
30
20
10
5
2.5


Scatter Graph
GF13A
Lanfear-Coll (HC=10.89)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

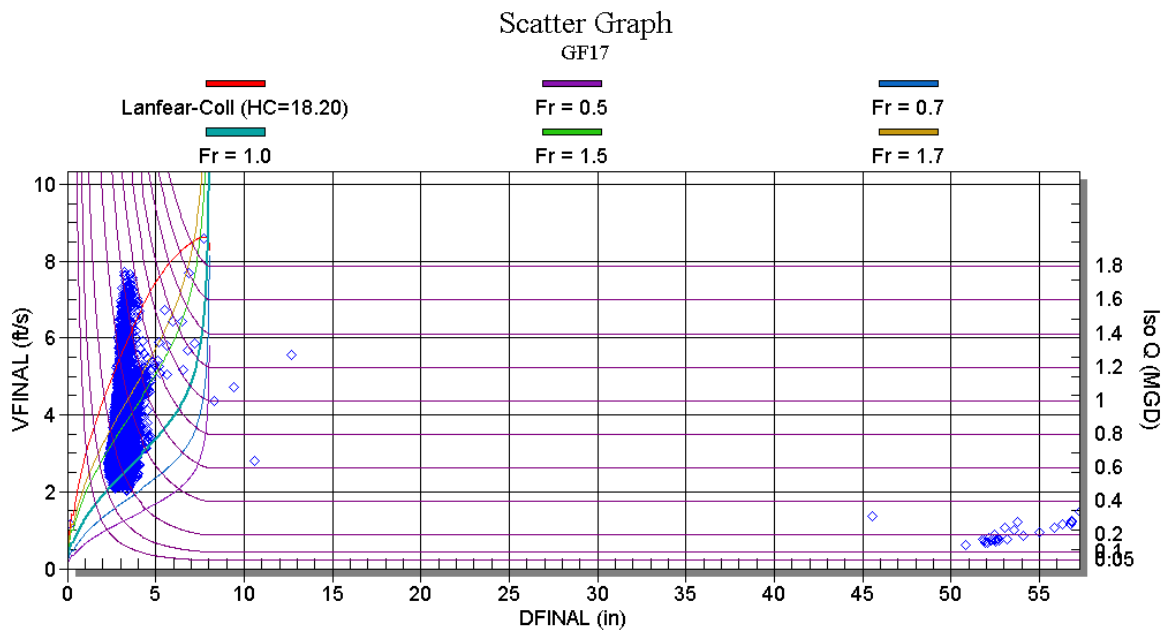

Scatter Graph
GF14
Lanfear-Coll (HC=3.35)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)



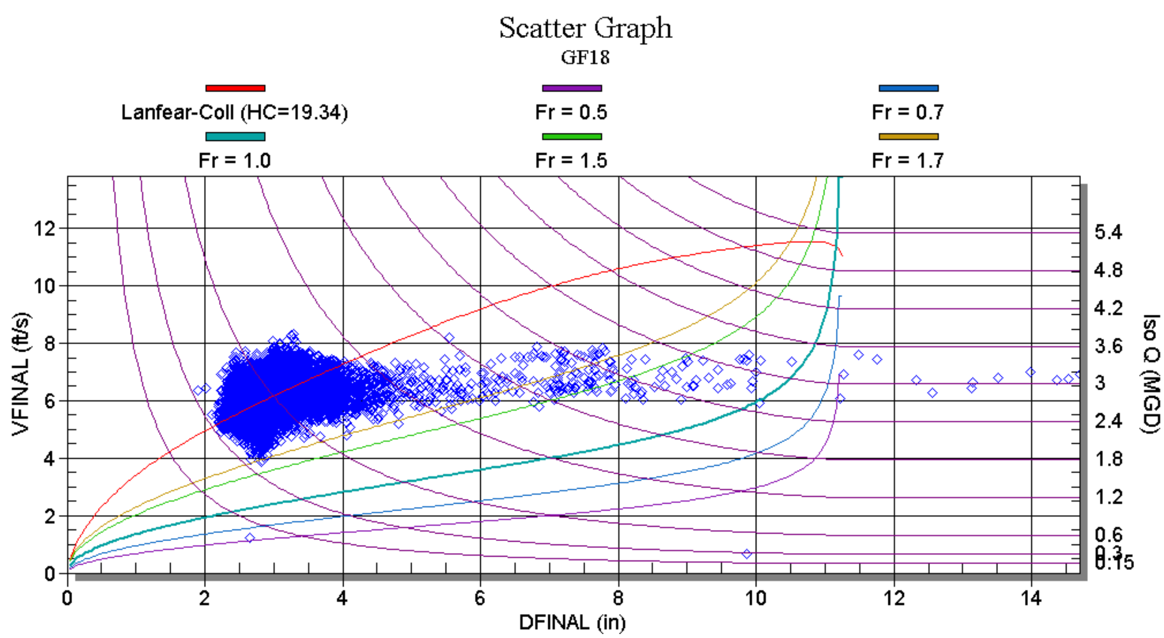
Scatter Graph
GF15
Lanfear-Coll (HC=10.75)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)



Scatter Graph
GF16
Lanfear-Coll (HC=7.36)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

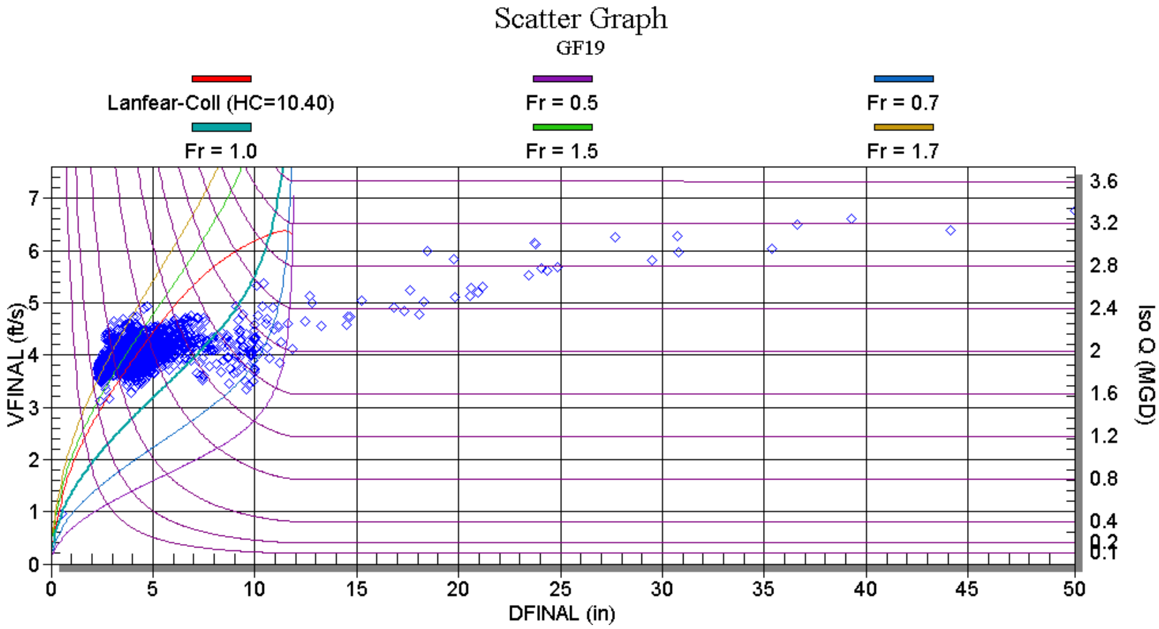


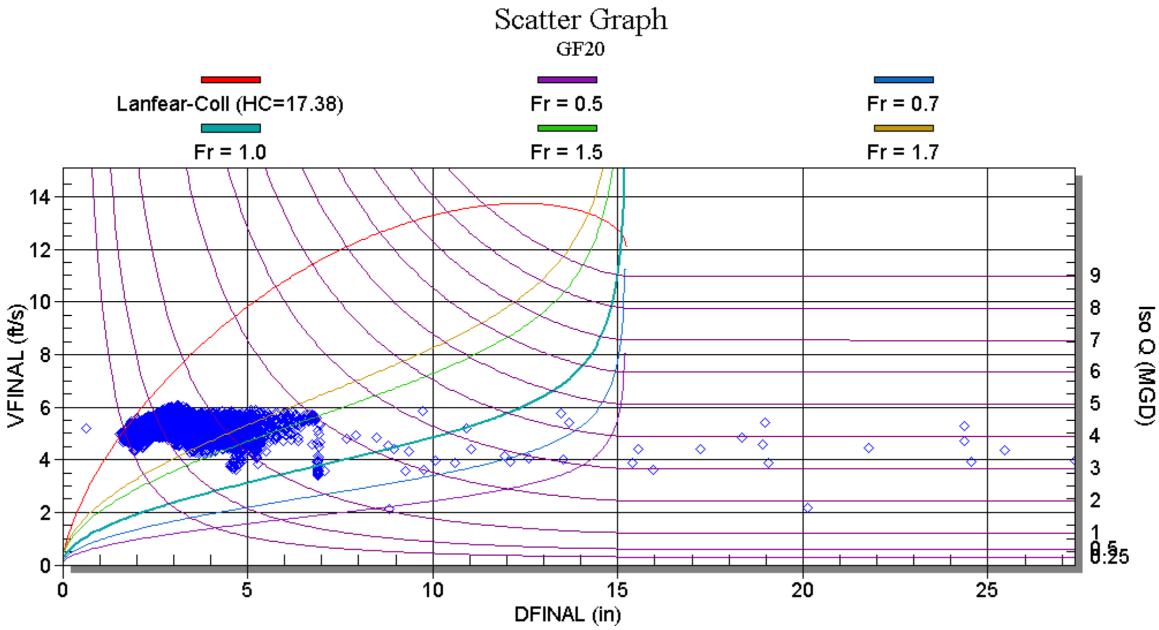
Scatter Graph
GF17
Lanfear-Coll (HC=18.20)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)



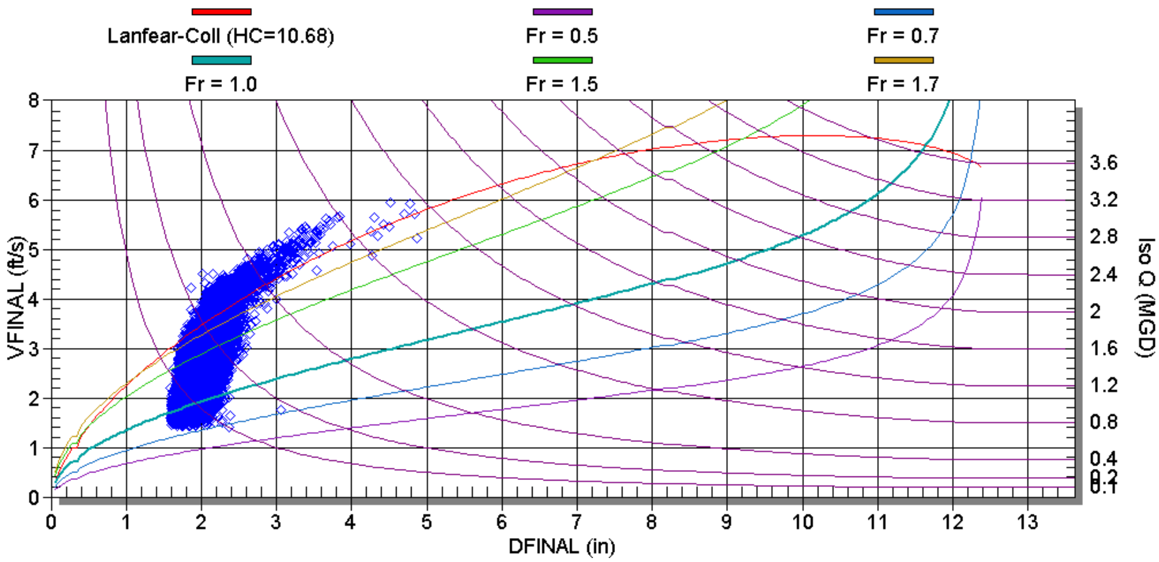
Scatter Graph
GF18
Lanfear-Coll (HC=19.34)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

Appendix 3-2

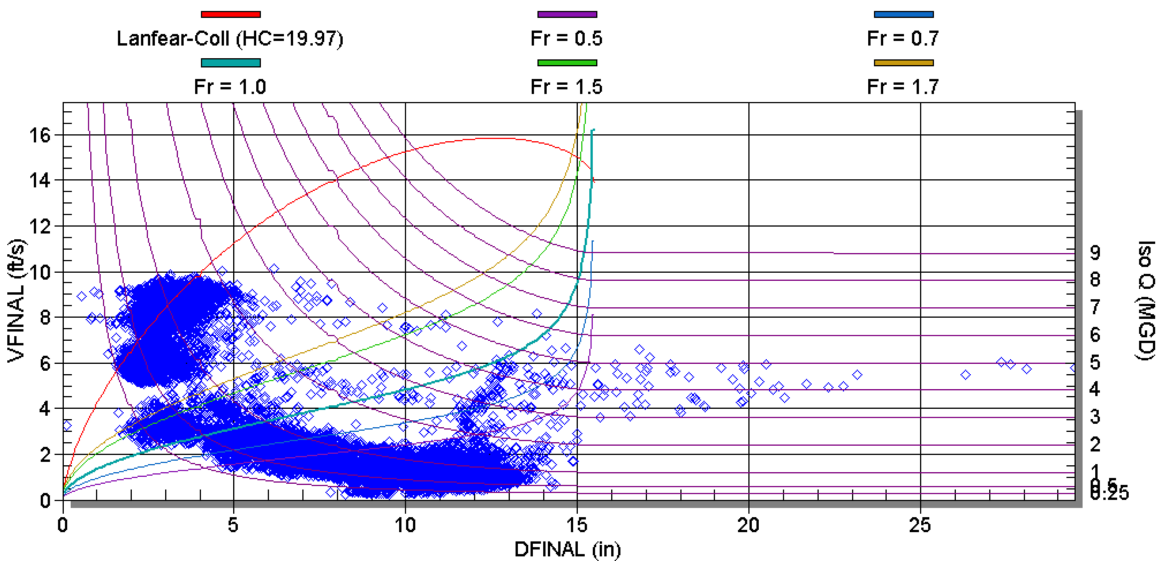

Scatter Graph
GF19
Lanfear-Coll (HC=10.40)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)


Scatter Graph
GF20
Lanfear-Coll (HC=17.38)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

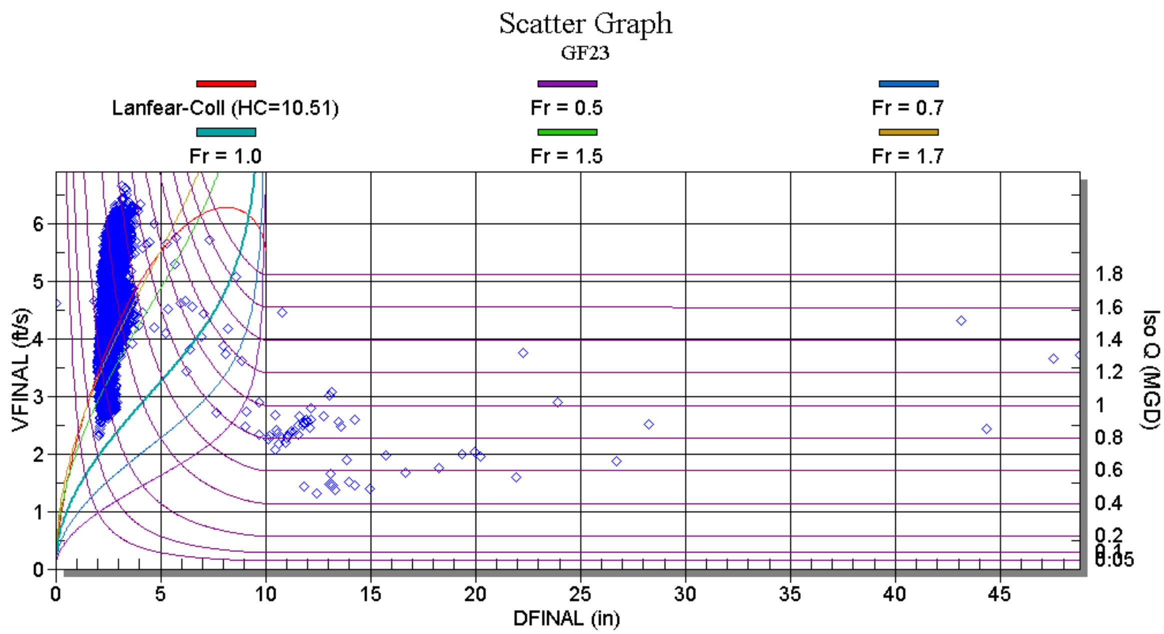
Scatter Graph
GF21



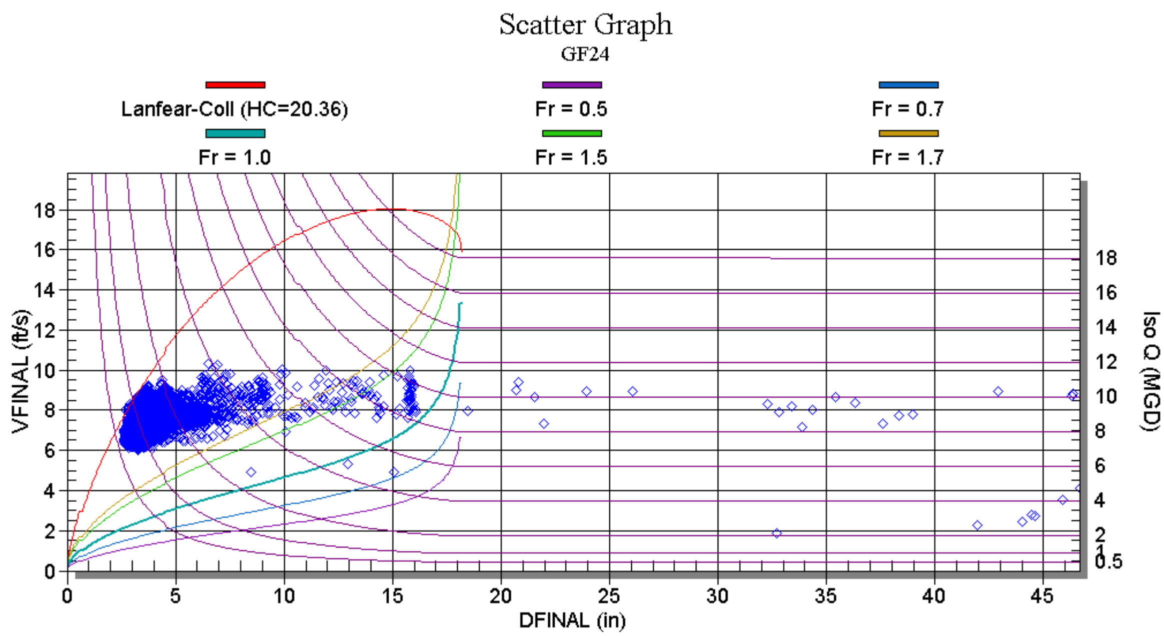
Scatter Graph
GF22



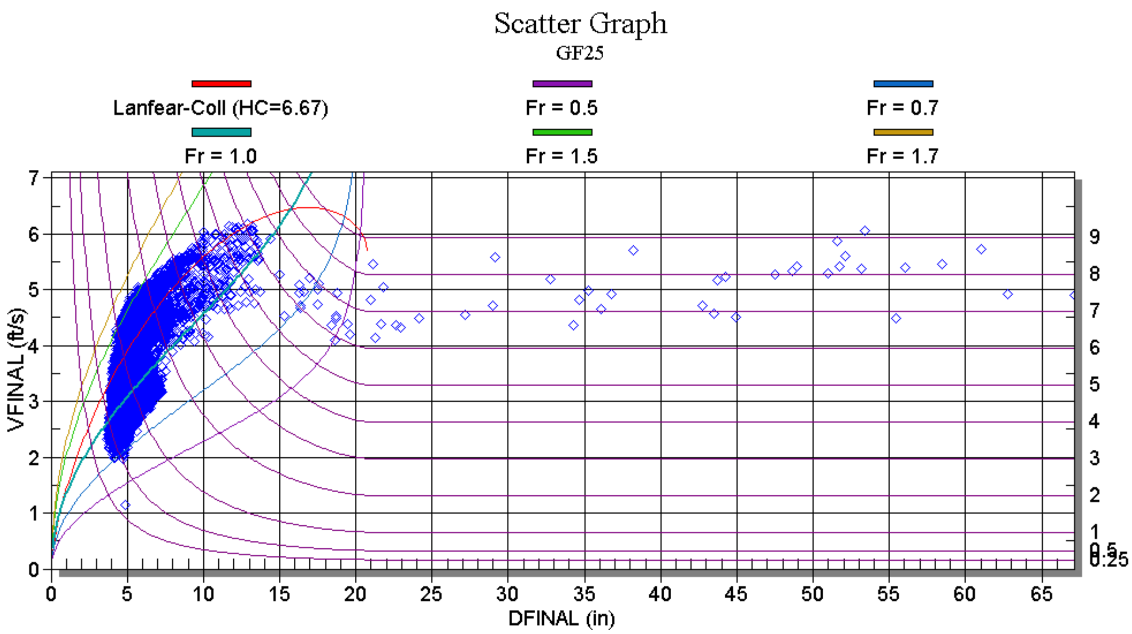
Appendix 3-2

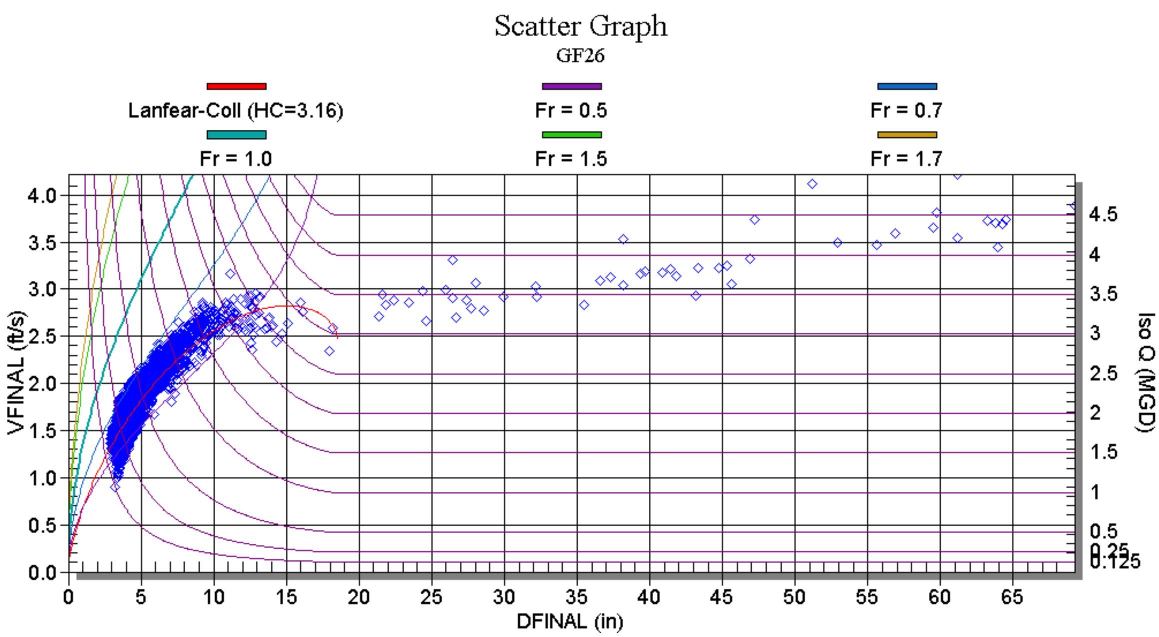


Scatter Graph
GF23
Lanfear-Coll (HC=10.51)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

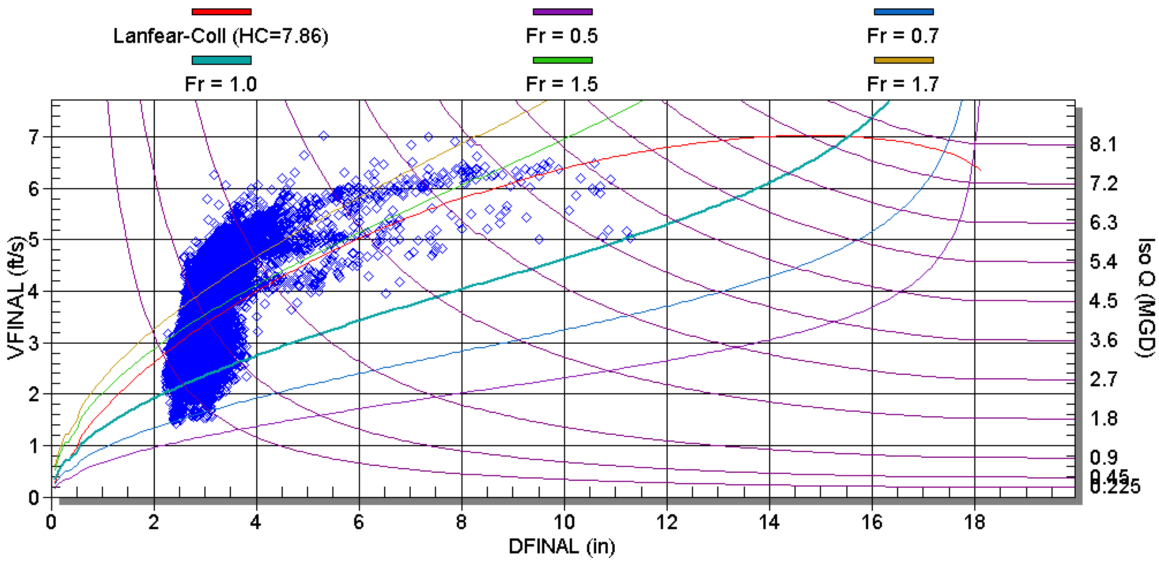


Scatter Graph
GF24
Lanfear-Coll (HC=20.36)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

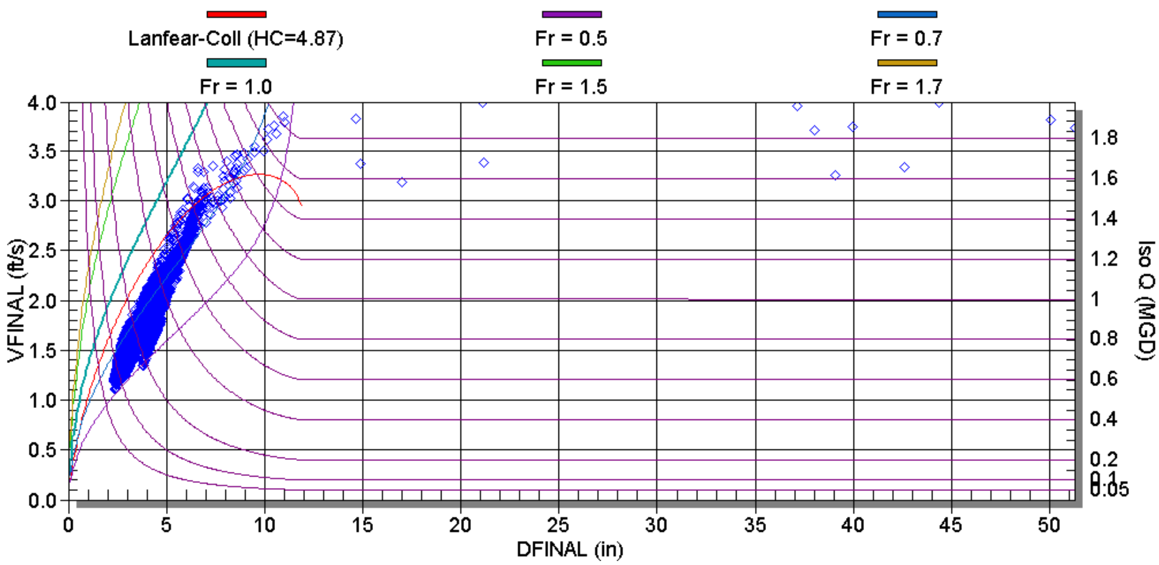

Scatter Graph
GF25
Lanfear-Coll (HC=6.67)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

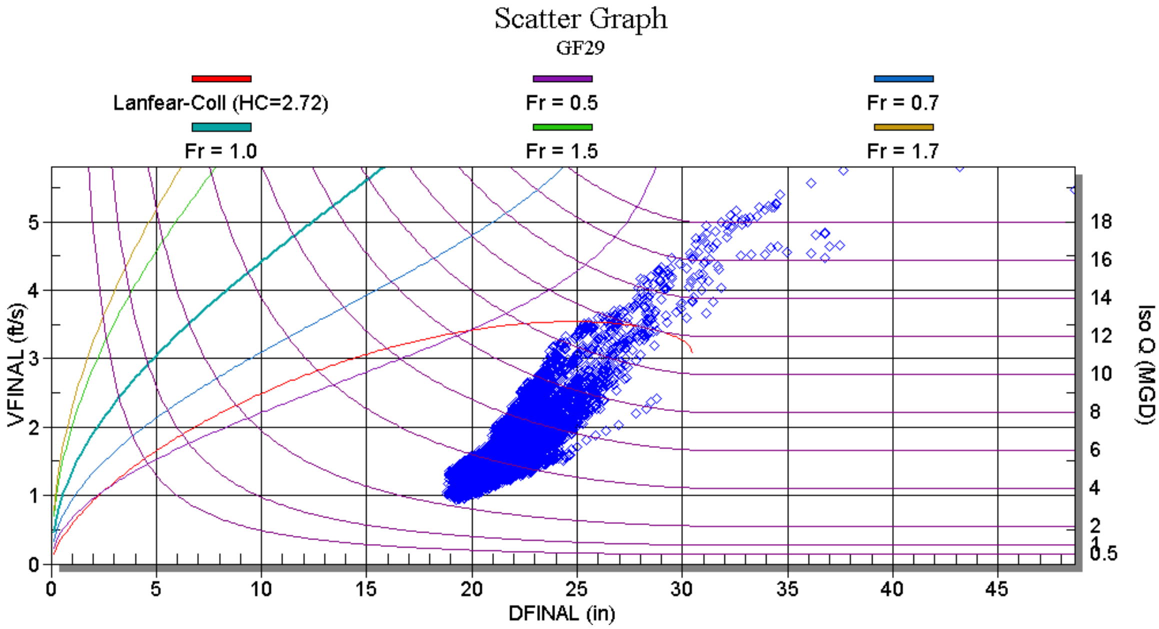

Scatter Graph
GF26
Lanfear-Coll (HC=3.16)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

Scatter Graph
GF27

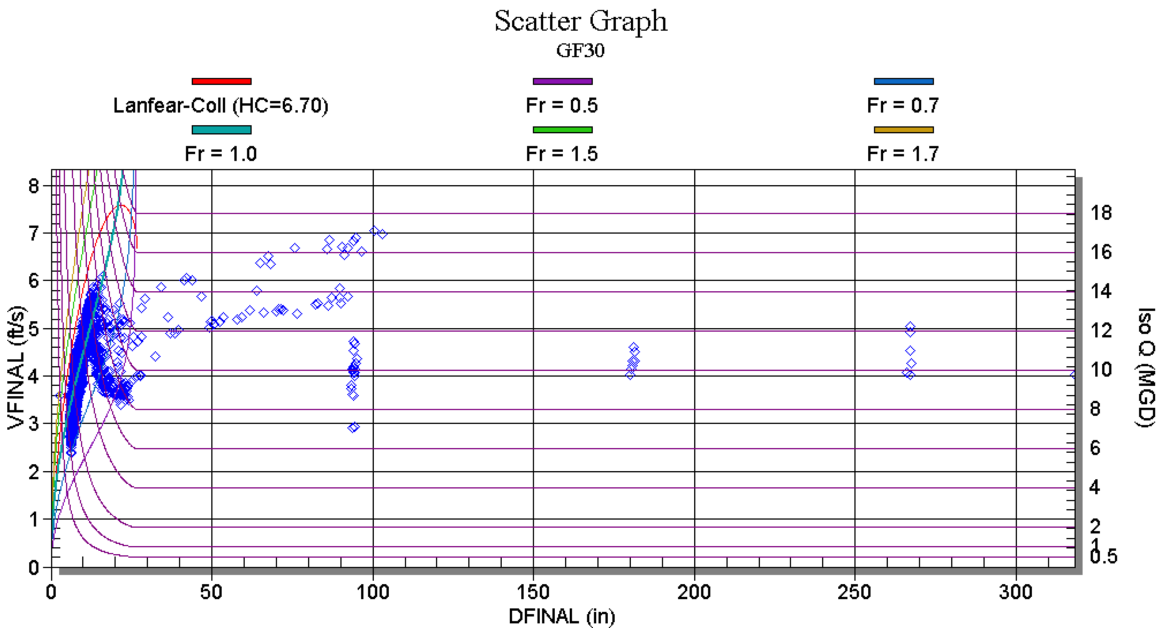


Scatter Graph
GF28



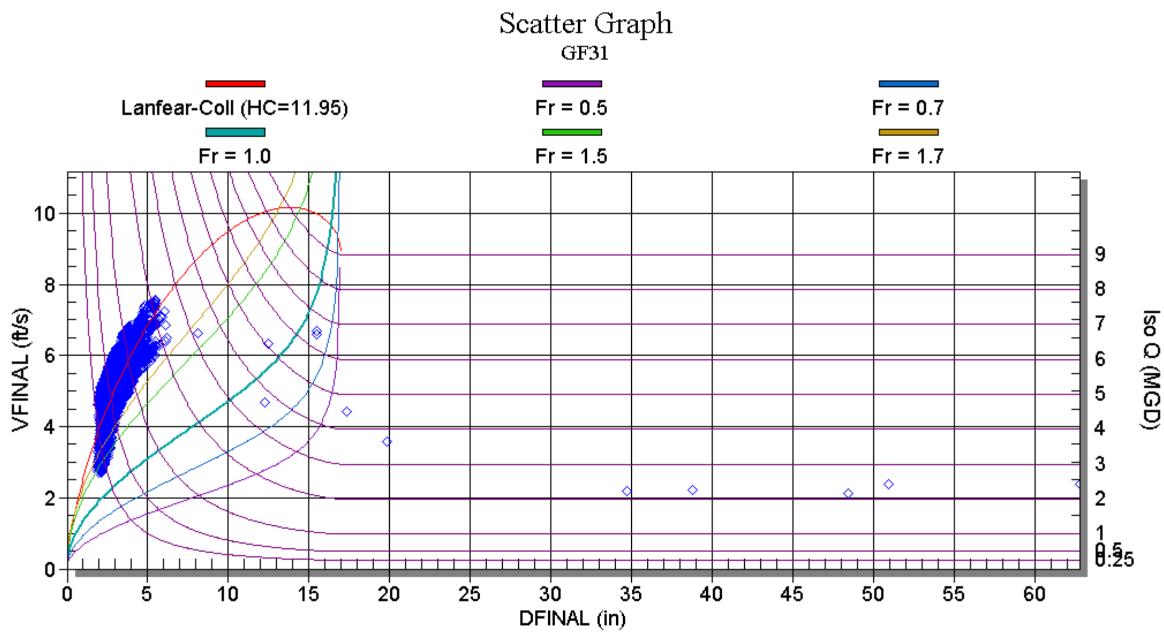


Scatter Graph
GF29
Lanfear-Coll (HC=2.72)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)
0
1
2
3
4
5
10
15
20
25
30
35
40
45
0.5
6
8
12
14
16
18

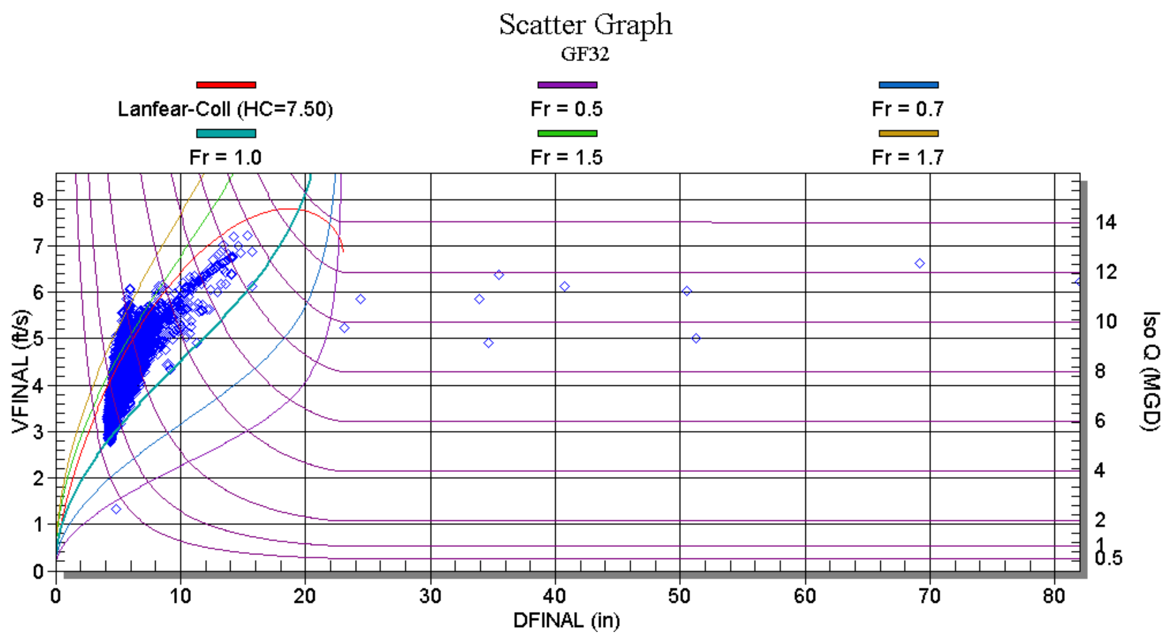


Scatter Graph
GF30
Lanfear-Coll (HC=6.70)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)
0
1
2
3
4
5
6
7
8
50
100
150
200
250
300
0.5
10
12
14
16
18

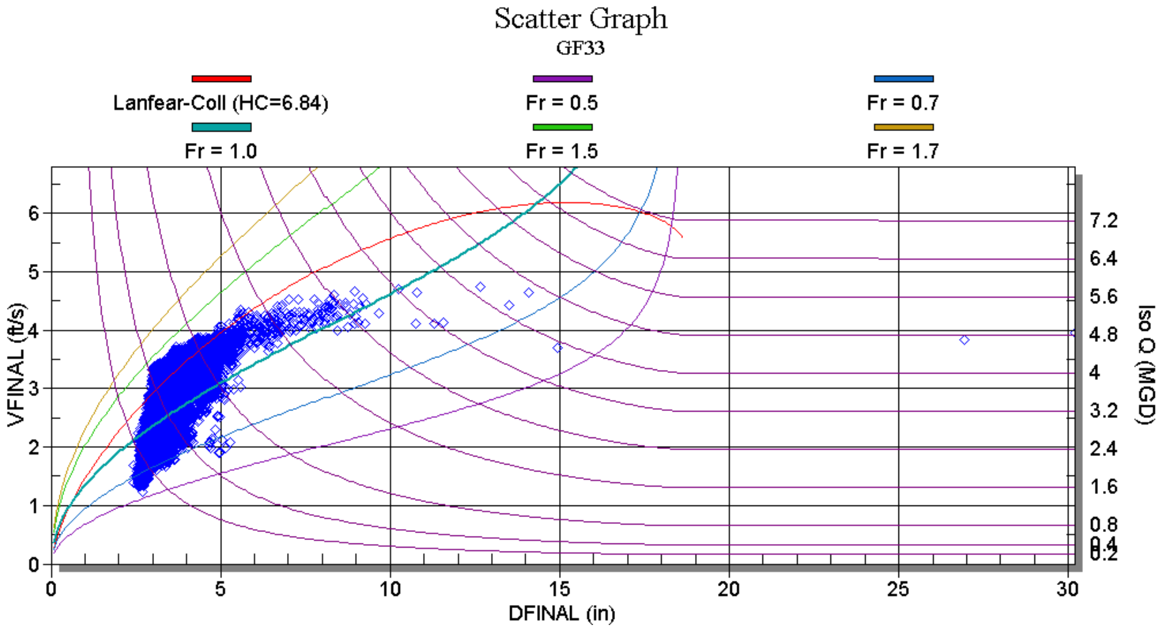
Appendix 3-2

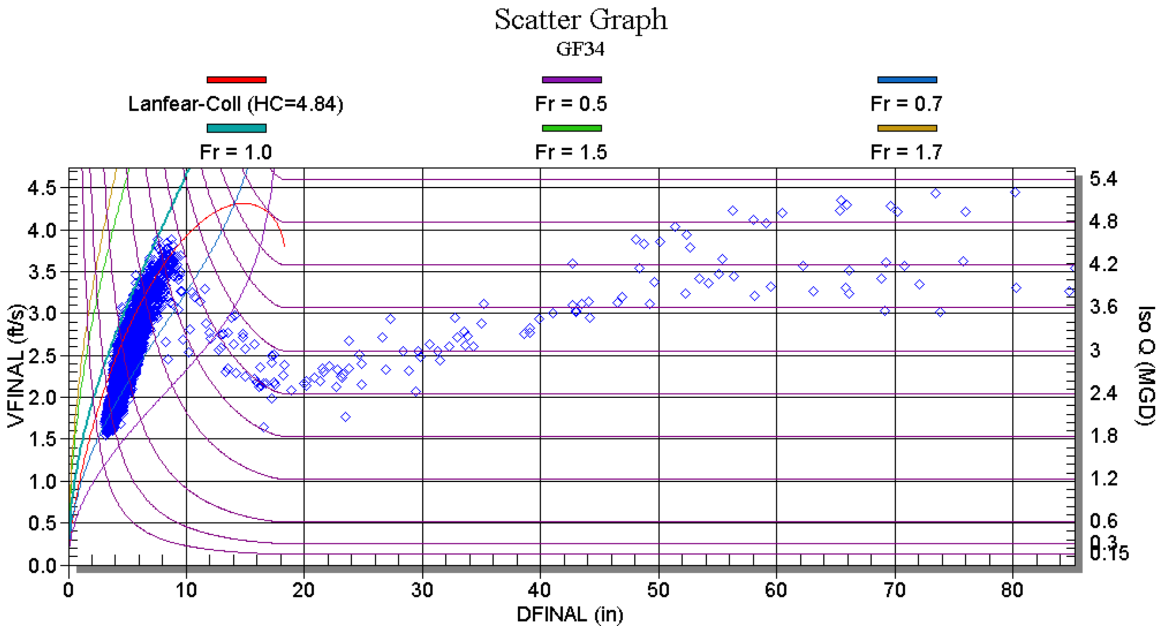


Scatter Graph
GF31
Lanfear-Coll (HC=11.95)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

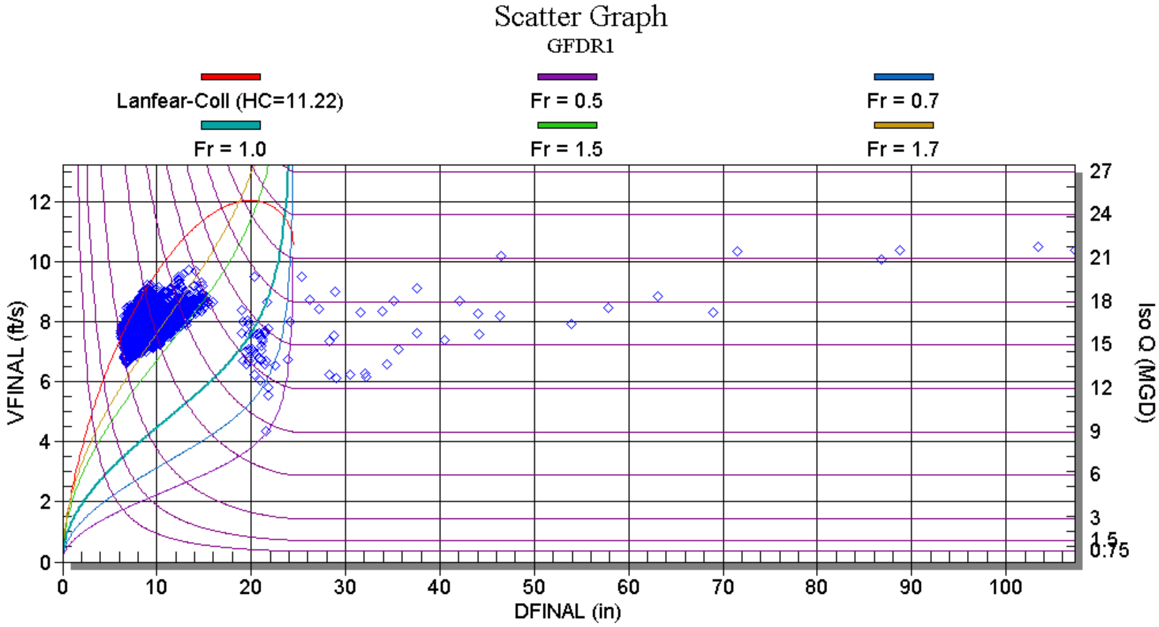


Scatter Graph
GF32
Lanfear-Coll (HC=7.50)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

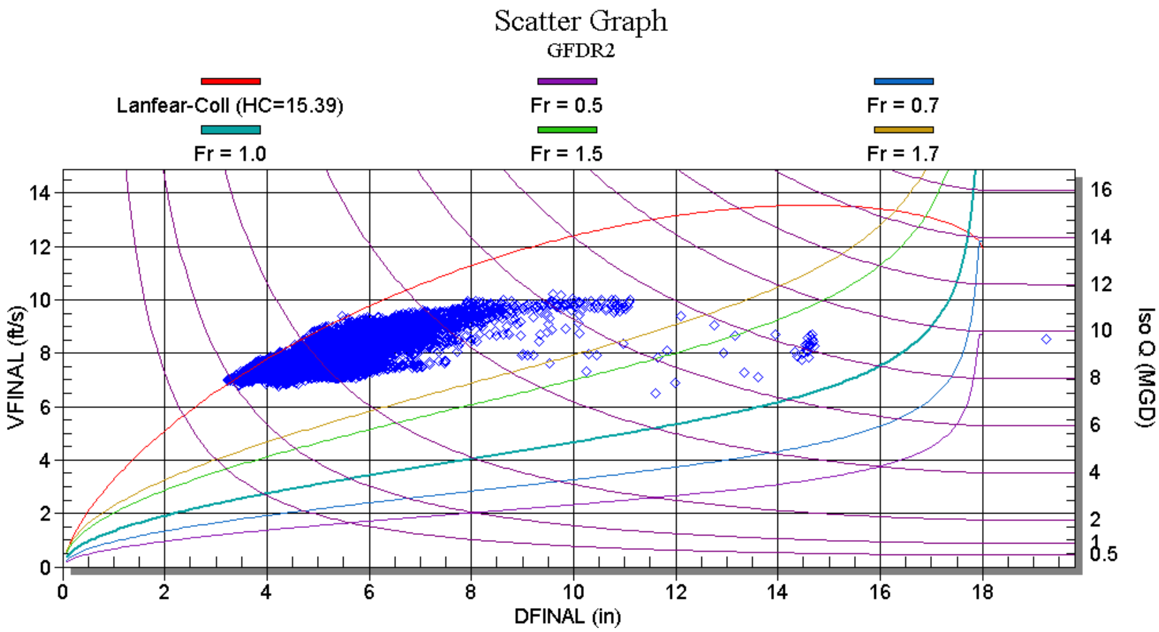

Scatter Graph
GF33
Lanfear-Coll (HC=6.84)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)


Scatter Graph
GF34
Lanfear-Coll (HC=4.84)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

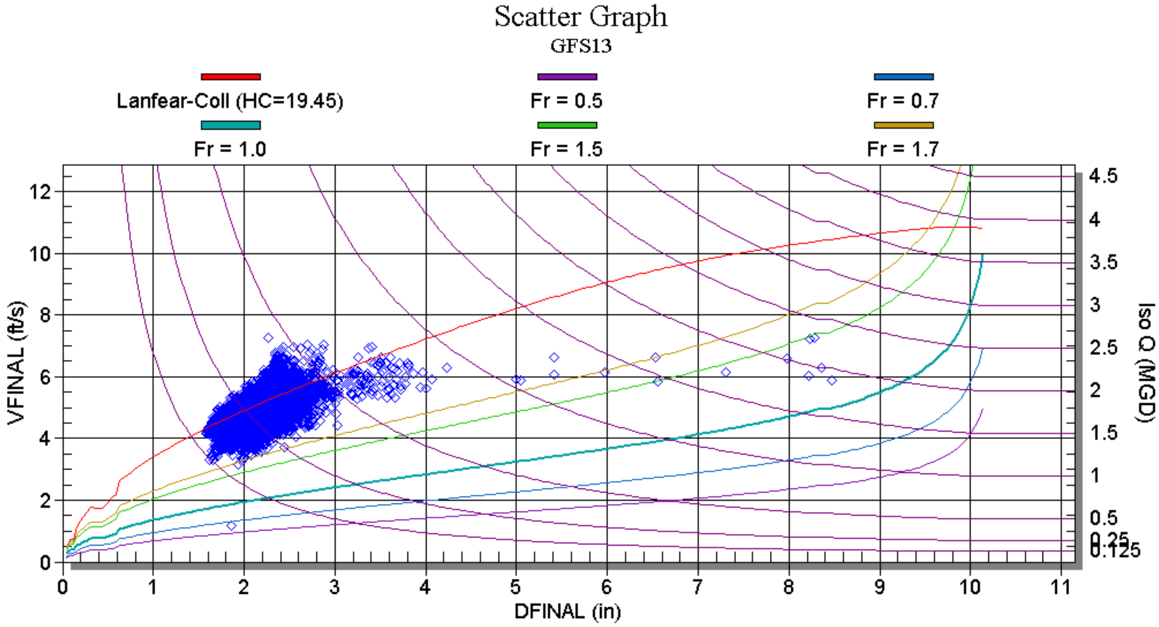
Appendix 3-2

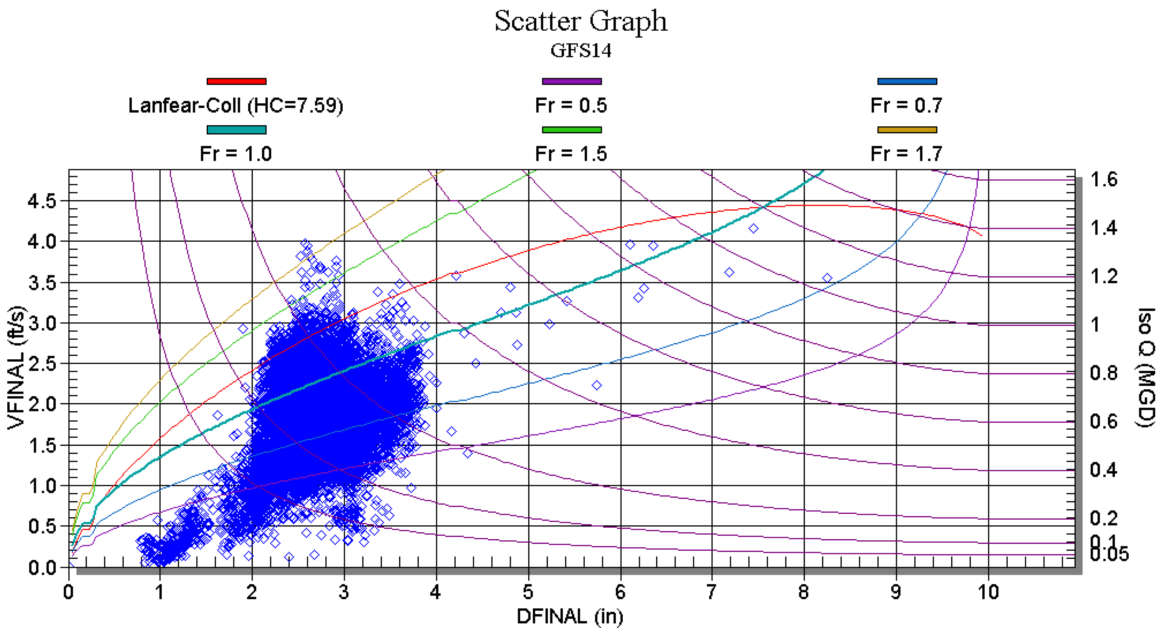


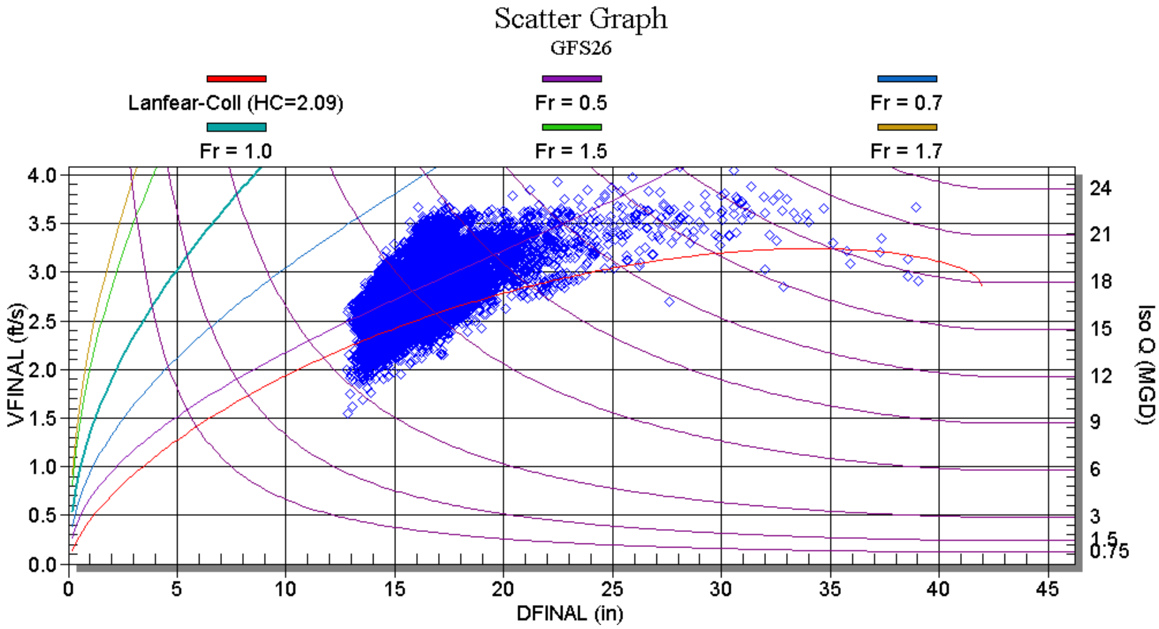
Scatter Graph
GFDR1
Lanfear-Coll (HC=11.22)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

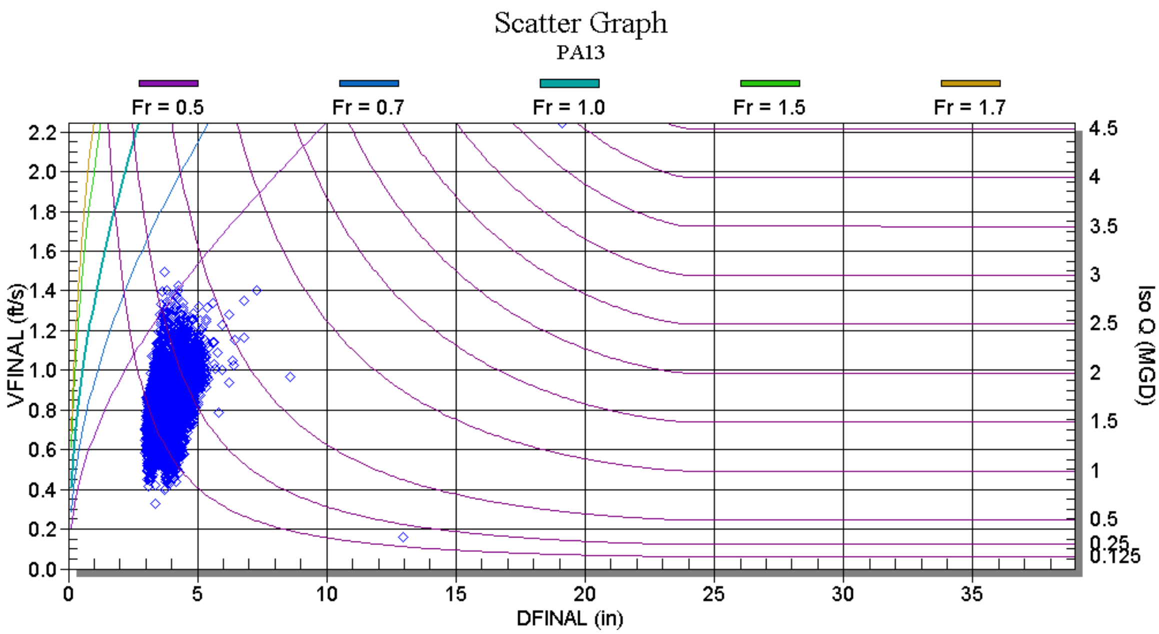


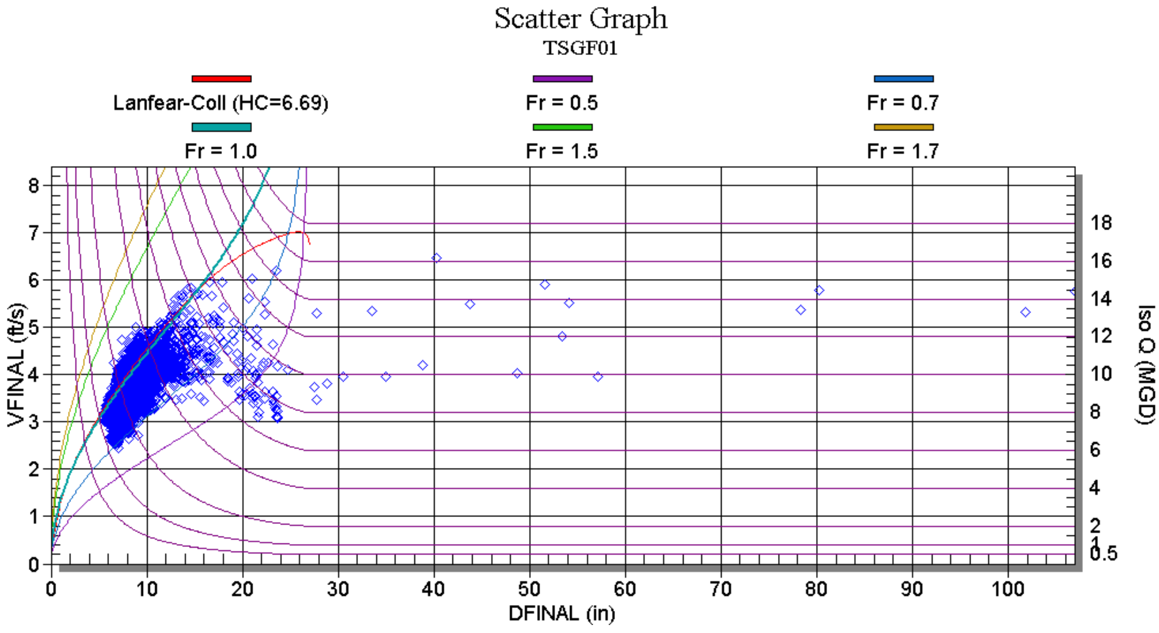
Scatter Graph
GFDR2
Lanfear-Coll (HC=15.39)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

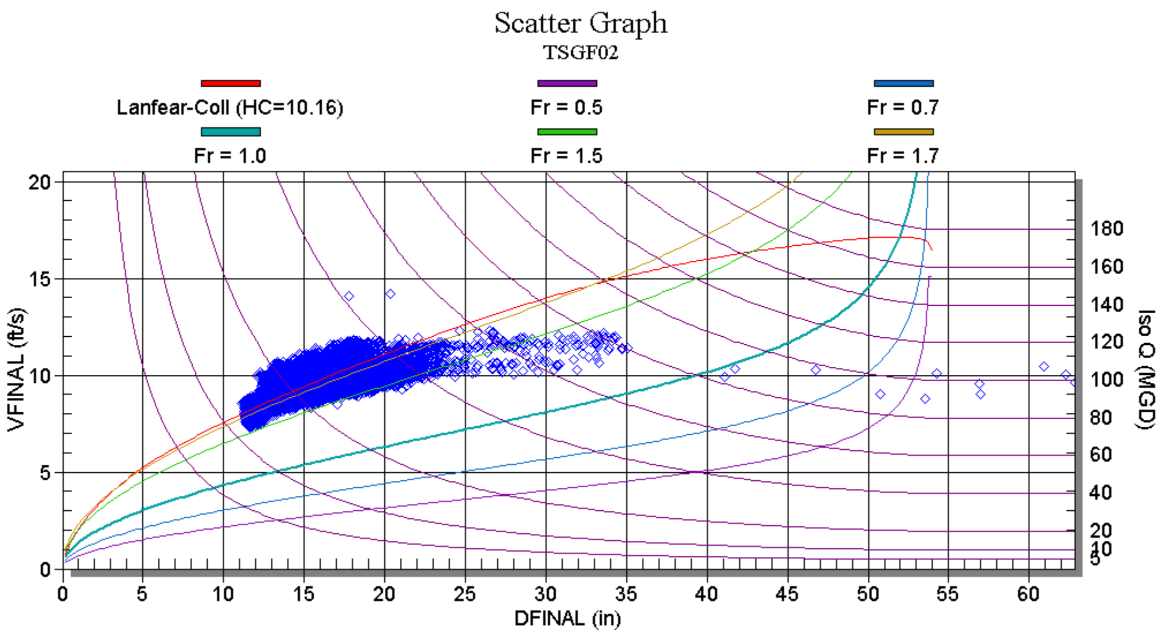

Scatter Graph
GFS13
Lanfear-Coll (HC=19.45)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

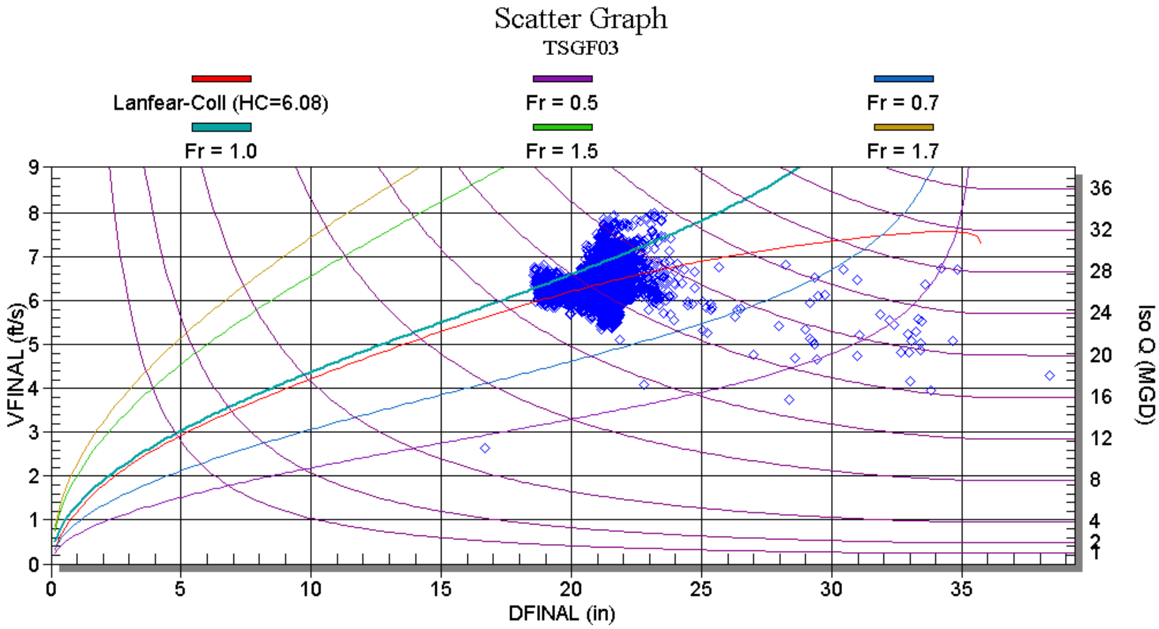

Scatter Graph
GFS14
Lanfear-Coll (HC=7.59)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

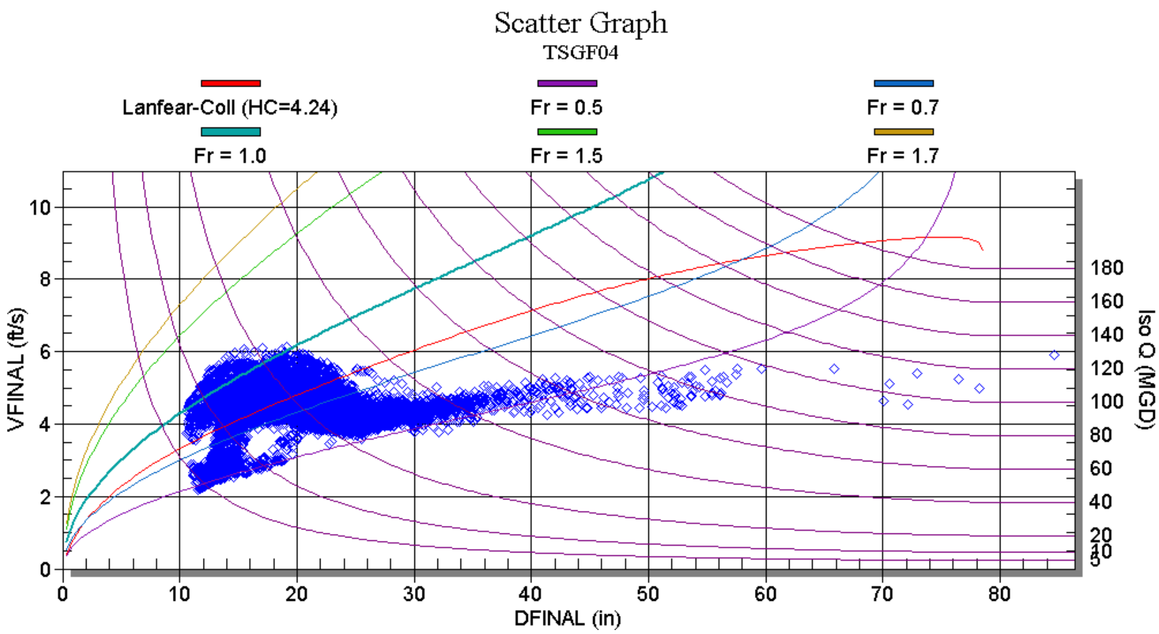

Scatter Graph
GFS26
Lanfear-Coll (HC=2.09)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)


Scatter Graph
PA13
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)


Scatter Graph
TSGF01
Lanfear-Coll (HC=6.69)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)


Scatter Graph
TSGF02
Lanfear-Coll (HC=10.16)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)


Scatter Graph
TSGF03
Lanfear-Coll (HC=6.08)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)


Scatter Graph
TSGF04
Lanfear-Coll (HC=4.24)
Fr = 0.5
Fr = 0.7
Fr = 1.0
Fr = 1.5
Fr = 1.7
VFINAL (ft/s)
DFINAL (in)
Iso Q (MGD)

TSPA01

NO SCATTER-GRAPH AVAILABLE